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Prototype Early Warning Fire Detection System: Test Series 1 Results

MARK T. WRIGHT
DANIEL T. GOTTUK
JENNIFER T. WONG

Hughes Associates, Inc.
Baltimore, MD

SUSAN L. ROSE-PEHRSSON
SEAN HART

Chemical Dynamics and Diagnostics Branch
Chemistry Division

FREDERICK W. WILLIAMS
PATRICIA A. TATEM
THOMAS T. STREET

Navy Technology Center for Safety and Survivability
Chemistry Division

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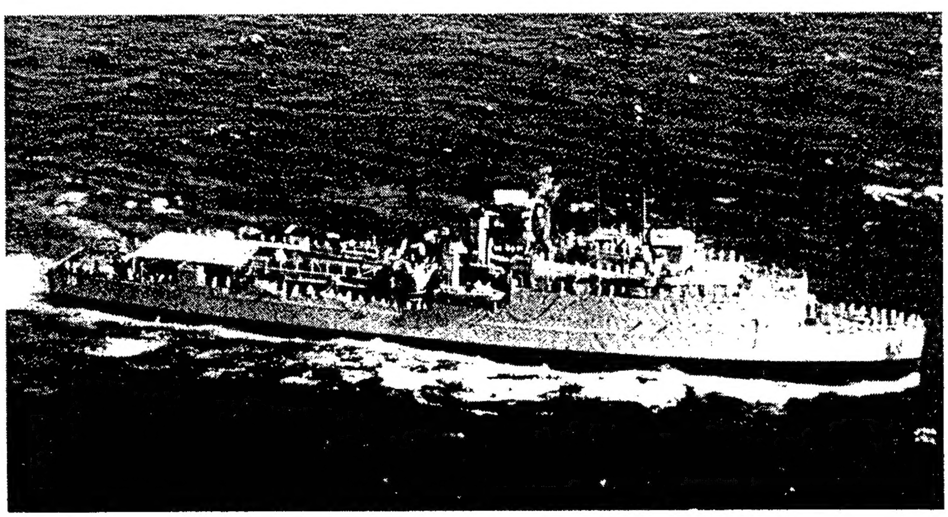

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Mark T. Wright,* Daniel T. Gottuk,* Jennifer T. Wong,* Susan L. Rose-Pehrsson, Sean Hart, Frederick W. Williams, Patricia A. Tatem, and Thomas T. Street

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13. ABSTRACT (*Maximum 200 words*)

This report documents the results of the Early Warning Fire Detection (EWFD) prototype Series 1 tests conducted on the ex-USS *Shadwell* over the period of February 7-18, 2000. Four EWFD prototypes were successfully integrated with a data acquisition system to operate in real time using a probabilistic neural network (PNN) and provided appropriate alarms in real time. Two prototypes were evaluated consisting of different sets of sensors and a PNN based on previous work in this program. EWFD prototype 2 demonstrated slightly better performance than EWFD prototype 1 and faster response times than the Simplex COTS smoke detection system. Even EWFD prototype 1 demonstrated on average faster response times than the Simplex detectors.

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PROTOTYPE EARLY WARNING FIRE DETECTION SYSTEMS: TEST SERIES 1 RESULTS

1.0 INTRODUCTION

This work is a continuation of a multi-year effort to develop an early-warning fire detection system that is highly immune to nuisance alarms. The work was conducted under the Office of Naval Research (ONR's) sponsored program Damage Control-Automation for Reduced Manning (DC-ARM) as part of a smart system capable of providing automated damage control. Over the past two years, efforts have focused on identifying appropriate sensors and candidate multivariate alarm algorithms [1,2]. This is the first of several field tests that have been designed to generate data for prototype and algorithm development. For this test, two prototype detection systems were assembled and algorithms written to produce real-time responses and alarms. The prototypes were tested in real-time onboard the ex-USS SHADWELL, the Naval Research Laboratory's full scale fire research facility in Mobile, Alabama [3]. The tests were conducted over the period of February 7-18, 2000.

The prototype fire detectors were to exposed to both real fire and nuisance sources while installed onboard the ex-USS SHADWELL in a typical space. The prototype detectors (i.e., the group of sensors that make up the detector) were monitored using a standard data acquisition system interfaced with a desktop computer. The data was processed in real-time to provide an output indicating either normal or fire conditions. The real-time sensor data and the output of the detection alarm algorithm were also transmitted over a recently installed fiber optic Ethernet for remote monitoring. Sensor outputs as well as algorithm results were stored and used to access the areas of improvement needed compard to commercial off the shelf instruments installed on the ex-USS SHADWELL. Several additional sensors were included in the tests for consideration in future prototype systems.

2.0 BACKGROUND

The system under development combines a multi-criteria (sensor array) approach with sophisticated data analysis methods. Together an array of sensors and a multivariate classification algorithm has the potential to produce an early warning fire detection system with a low nuisance alarm rate. Several sensors measuring different parameters of the environment produce a pattern or response fingerprint for an event. Multivariate data analysis methods can be trained to recognize the pattern of an important event such as a fire. Multivariate classification methods, such as neural networks, rely on the comparison of events (i.e., fires) with nonevents (i.e., background and nuisance sources). Variations in the response of sensors can be used to train an algorithm to recognize events when they occur. A key to the success of these methods is

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the appropriate design of sensor arrays and training sets of data used to develop the algorithm. This test series included a variety of conditions that may be encountered in a real shipboard environment. Every effort was made to consider many representative fire situations and potential interference sources, including the use of Navy approved materials.

3.0 OBJECTIVES

The specific objectives of this test series were to:

1. produce two candidate prototypes with a data analysis system that can operate in real-time,
2. collect data for further development of prototypes and algorithms,
3. evaluate the performance of the two prototype systems to correctly classify real fire and nuisance sources for algorithm and prototype optimization,
4. evaluate detection performance with respect to detector spacing (i.e., distance from source), and
5. use the fiber optic LAN based Ethernet to transmit data to remote sites such as the Control Room.

4.0 EXPERIMENTAL TESTING

Prototype detection systems were installed in the forward area of the ship on the second deck in the compartments between Frames 15-29. The test area is depicted in Figure 1.

The forward space from Frames 15-22 is designated CIC, the starboard space from Frames 22-27 is designated the Operations Office (Ops Office) and the space surrounding the Ops Office is designated the Combat Systems Office. The Ops Office was the primary fire compartment. The source fires/nuisances consisted of those used during previous tests [1,2] as well as several new sources that transition from a nuisance to a fire. The primary locations of the fire/nuisance sources are also shown in Figure 1 as Location 1 and Location 2. The placement of the detectors is indicated in the figure as Location A and Location B.[M.W.1]

4.1 Fire Scenarios

This section describes the various fire scenarios selected for testing in this program. A summary table of these scenarios is provided in Table 1. Unless stated otherwise, all scenarios were conducted in the Ops Office.

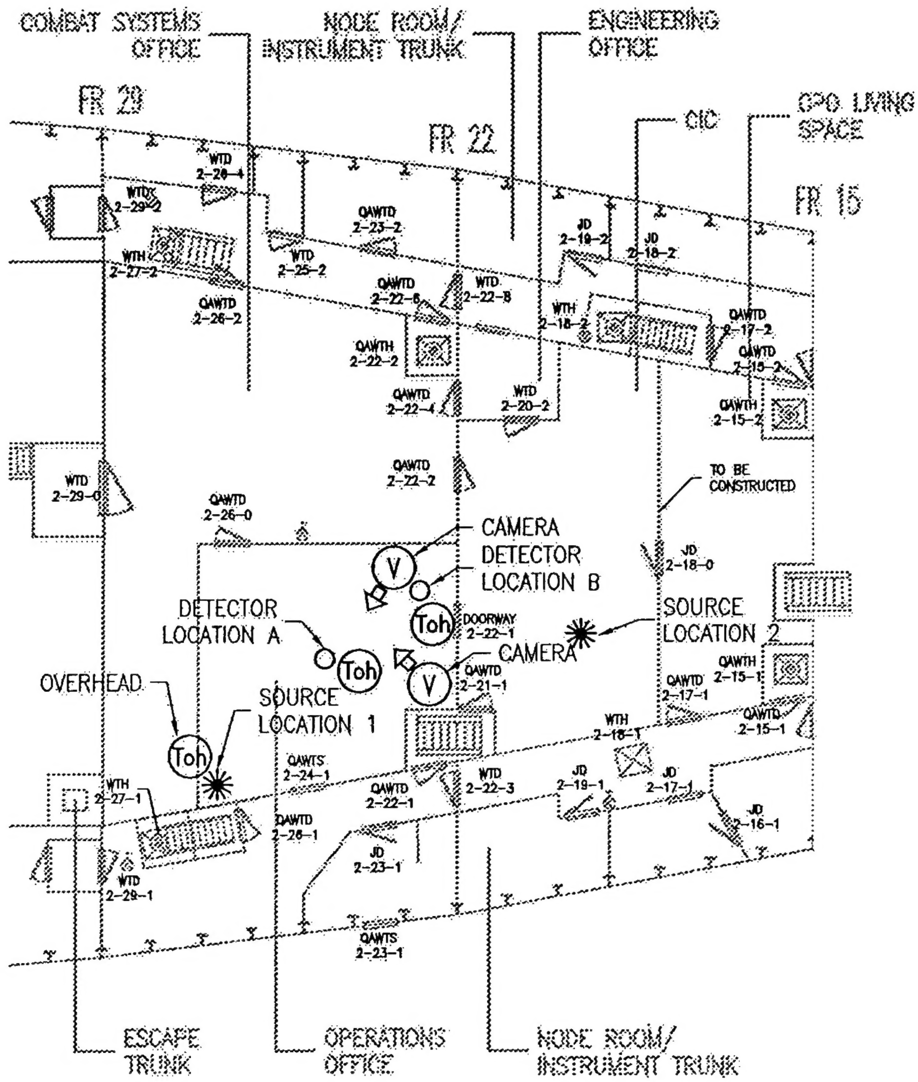

Figure 1. Plan view of test area on second deck.

Table 1. Summary of fire scenarios.

Fire Scenario	*Description*	*Location*
F01	Heptane Pool Fire	Ops Office
F02	Pipe Insulation Exposed to Fuel Oil Fire	Ops Office
F03	Flaming Oily Rag in Small Trash Can	Ops Office
F04	Smoldering Oily Rag in Small Trash Can	Ops Office
F05	Smoldering Plastic Trash Bag	Ops Office
F06	Plastic Trash Bag Fire next to TODCO Wallboard	Ops Office
F07	Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire	Ops Office
F08	Smoldering Electrical Cables	Ops Office
F09	Smoldering Bedding Material	Ops Office
F10	Flaming Bedding Material	Ops Office
F11	Printed Wire Board Fire	Ops Office
F12	Small Wood Crib Fire	CIC
F13	Metal Trash Can Fire next to Office Chair	CIC
F14	Brief Wire Overheat	Ops Office

4.1.1 Scenario 1 – Heptane Pool Fire

A small heptane pool fire was used periodically to determine the reproducibility and the stability of the sensors during the test series. Heptane is a typical hydrocarbon fuel used in standardized tests. Approximately, 260ml (8.8fl.oz) of heptane in an 11.4cm (4.5in) diameter pan was ignited with a torch. The bottom of the pan was located 0.6m (2ft) above the deck.

4.1.2 Scenario 2 – Pipe Insulation Exposed to a Fuel Oil Fire

Calcium silicate insulation with glass cloth lagging pipe insulation was exposed to an F-76 fuel oil fire. The insulation was obtained from Reilly Benton Insulation Co., a Navy supplier. The calcium silicate sample (MIL-I-278) was 2in (5.1cm) internal pipe size and 1in (2.54cm) thick. The glass lagging cloth (MIL-C-20075, Ty CL 3, Reilly Benton Type 300) was applied to the calcium silicate with MIL-A-3316 Class I Grade A adhesive (Vimasco 713).

The insulation was cut in approximately 45cm (18in) long samples and mounted around PVC pipe with corresponding diameters. The lagging was then applied around the insulation per the manufacturer's instruction. After assembly, samples were painted with chlorinated Alkyd White, DOD-E-24607, Color 27880.

The insulation and pipe assembly was exposed to an F-76 flame from 11.4cm (4.5in) diameter fuel pan. The fuel pan contained 260 ml (8.8fl.oz) of F-76 fuel oil with 20ml (0.7fl.oz) of ethyl alcohol accelerant. The pipe assembly was mounted horizontally, 10cm (4in) above the top of the pan. The bottom of the pan was 1.2m (4ft) above the deck. This test was conducted

three times, twice with F-76 as the initiating source and once with heptane. The heptane was used as a cleaner-burning intiating source, so that the detectors would be more exposed to the combustion products of the pipe insulation material.

4.1.3 Scenario 3 – Flaming Oily Rag and Paper in Small Trashcan

A 6 L (1.6 gal) metal trashcan contained five full sheets of newspaper, two pieces of $0.4m^2$ ($4ft^2$) cardboard, and one $0.1m^2$ ($1ft^2$) cotton rag saturated with 118ml (4fl.oz) of 10W30 motor oil. The cardboard was rolled loosely to fit into the trashcan, and the newspaper was folded, slightly crumbled, and placed in the center of the cardboard. The oily rag was between the cardboard and the newspaper. Both times this scenario was conducted, a butane lighter was used to ignite the oily rag. The bottom of the trashcan was 0.6m (2ft) above the deck.

4.1.4 Scenario 4 – Smoldering Oily Rag and Paper in Small Trashcan

A 6 L (1.6 gal) metal trashcan contained five full sheets of newspaper, two pieces of $0.4m^2$ ($4ft^2$) cardboard, and one $0.1m^2$ ($1ft^2$) cotton rag saturated with 118ml (4fl.oz) of 10W30 motor oil. The arrangement of materials in the trashcan was the same as described in the previous scenario. A 2.5cm (1in) diameter hole, 2.5cm (1in) above the bottom of the trashcan, was drilled into the side of the trashcan. A 14.7cm (5.5in) Calrod [Ogden Model MWEJ05J1870, 700Watt, 125Volt] was inserted into the hole of the trashcan. About 90% of the length of the Calrod was allowed to rest on the oily rag. The Calrod was energized via a variac to 50% of capacity. The bottom of the trashcan was 0.6m (2ft) above the deck. This test was conducted twice.

4.1.5 Scenario 5 – Smoldering Plastic Bag of Mixed Trash

A plastic trashbag contained various typical waste items, such as paper towels, newspaper, cans, food containers, fruit, and banana peels. The sources were actual trash bags and contents obtained from the crews mess deck onboard the ship. The dimensions of the bag were 2m (6.5ft) in circumference and 0.9m (3ft) deep. The bag was placed 0.6m (2ft) above the deck in a pan, and exposed to a 5.5in (14.7cm) Calrod placed between the bag and the side of the pan. The variac controlling the Calrod was initially set to 50% of capacity. During the first trial of this scenario, the Calrod was increased to 100% capacity about 42 minutes after the Calrod was initially energized. This was done to increase the smoldering rate and ignite the trashbag. This test was conducted a second time, where the Calrod was initially set to 75%. This power level caused flaming ignition of the trashbag, without the need to increase the Calrod power. In both tests, the Calrod was turned off and removed once flaming ignition occurred.

4.1.6 Scenario 6 – Flaming Plastic Bag of Mixed Trash next to TODCO Wallboard

A plastic trashbag as described in Scenario 5 was placed next to the wallboard. The trashbag was placed in a pan and ignited with a butane lighter. The base of the trashbag was 0.6m (2ft) above the deck. This scenario was conducted twice.

The white, TODCO Engineering Products, Nomex panel used in this test was a non-filled honeycomb with phenolic resin impregnated fiberglass facing over the aramid fiber honeycomb core. The dimensions of the sheet used were 0.6m x 0.6m (2ft x 2ft) and the honeycomb was 0.6cm (0.25in) hexagonal MIL SPEC MIL-C-81986, with a density of $48kg/m^3$ ($3lb/ft^3$). The overall panel thickness was 1.6cm (+0.000cm, - 0.08cm) (0.625in. (+0.000in., -0.030in.)) thick including the decorative face sheets. The decorative face sheets were high pressure laminate (HPPL) in accordance with MIL SPEC MIL-P-17171, Type IV except that they were 0.07cm - 0.09cm (0.027in - 0.037in) thick. The HPPL was bonded directly to the fiberglass face sheet using the phenolic resin system per MIL SPEC MIL-R-9299, Grade A.

4.1.7 Scenario 7 – Electrical Cables and Pipe Insulation exposed to a Laundry Pile Fire

Electrical cables and pipe insulation (as described in Scenario 2) were exposed to a laundry pile fire. Four 1m (39in) lengths of LSDSGU-14 cable were vertically supported next to a 0.5m (19.5in) vertical section of insulated pipe. The 9AWG, 2 conductor cable was manufactured by Monroe Cable Co, Military Part No. M24643/15-03UN. The cable consisted of crosslinked polyolefin jacket with silicon rubber insulation on the conductors. The laundry pile consisted of 3 pairs boxer shorts, 3 shirts, a pair of briefs, and a towel (all items were 100% cotton, with the exception of the elastic in the waistbands). The fire was initiated at the base of the laundry pile, between cable/pipe insulation and the pile. The base of the laundry pile was 0.6m (2ft) above the deck.

4.1.8 Scenario 8 – Smoldering Electrical Cables

This test simulated a long smolder of the LSDSGU-14 cable described in Scenario 7 (length of 33cm [13in]). The jacket and insulation were stripped back on both ends exposing 1.25cm (0.5in) of both conductors. The arc welder was clamped to both conductors on one end of the cable and the other end was grounded to a metal stand via a clamp. After initial background data was collected, the arc welder was energized to 375 A. The cables remained energized until the end of the test. The result was the slow heating of the cable that produced light smoke until the insulation broke, causing the smoke to become heavier. However the amount of smoke seemed to cycle with the power of the arc welder, as increasing smoke was noted with the sound of the welder ramping up its power, and decreasing smoke was noted as the sound of the welder indicated that it was ramping down in power.

4.1.9 Scenario 9 – Smoldering Bedding Materials

A Navy mattress (MIL-M-18351F(SH)) consisting of a 11.4cm (4.5in) thick Safeguard polychloroprene foam core covered with a fire retardant cotton ticking was outfitted with the following items:

1) Two sheets - Federal Specification DDD-S-281,
2) One blanket - Federal Specification MIL-B-844, and
3) One bed spread - Federal Specification DDD-B-151.

4) One mock-up pillow – A Navy feather pillow (Federal Specification V-P-356, Type 4) and a pillowcase (Federal Specification DDD-P-351) were cut and stapled into a 6 in x 6 in (15 cm x 15 cm) sample.

The composite fuel source was cut into 6 in x 6 in (15 cm x 15 cm) squares and layered in the following order (from the bottom up): mattress, sheets, blanket, bed spread, pillow.

The smoldering fire source consisted of placing one square sample 1.2m (4ft) above the deck, with a 700W Calrod resting on the center between the bed spread and the pillow. The Calrod was energized with a variac to 50% of capacity, and was allowed to rest on the sample under its own weight, remaining energized for the duration of the test. This test was conducted twice.

4.1.10 Scenario 10 – Flaming Bedding Material

The same bedding sample setup from Scenario 9 was used in this test. One sheet of crumpled newspaper placed on top of the pillow was used as the initiating source for this fire. A butane lighter was used to ignite the newspaper. The response of the detectors in this scenario was fast enough (60-90seconds) that the alarm state was probably caused by the burning newspaper as opposed to the burning bedding material. The burning newspaper caused the pillow to smolder, which subsequently caused flaming combustion of the feathers in the pillow.

4.1.11 Scenario 11 – Printed Wire Board Fire

Internal PWB failures are also a fairly common event in electronic equipment. These are generally caused by contaminates within the PWB, a by-product of the manufacturing process, but can also be induced by component failures and/or power surges. In reference [5], a printed wiring board (PWB) test was specially designed to replicate fires in circuit boards. The test board was fabricated with two parallel 50 mil wide tracks, spaced 50 mil apart. The tracks extended to one end of the 41-cm long board where solder coated pads were provided to connect the circuit to the power supply. At the opposite end of the 38 cm long tracks, a 10 mil wide track bridged the long tracks to complete the circuit and provide a short length of higher resistance track where localized heating could develop and in time lead to the formation of an arc. The test board was fabricated of FR-4 substrate material, and the board was coated with dry film solder mask, materials typical of those used in telecommunications equipment manufacture.

The overheated power tracks, aligned parallel to one another, pyrolyze or carbonize the substrate material between them. After a time, the insulating properties of the material are sufficiently degraded that an arc develops between the two tracks, igniting the gaseous pyrolosis products. A flame about ½ inch tall results, and travels along the tracks with the progressing arc. The process is self-sustaining as long as power is applied to the circuit. The arc travels along the tracks starting at the point of ignition and moves closer to the connecting pads at the end of the PWB.

The test PWB was mounted vertically in a stand (1.2m (4ft) above the deck) with the tracks aligned parallel to the floor, and connected to the leads of a Kenwood model PD18-3AD regulated DC power supply. The tests were conducted with the regulated DC power supply set to deliver a constant current of 8.5 A with a peak voltage setting of 6.0 V.

4.1.12 Scenario 12 – Small Wood Crib Fire

A small wood crib was constructed with four layers of wooden sticks, with 3 sticks in each layer and the stick direction alternating on each level. Each stick was 5.1cm x 5.1cm x 20cm (2in x 2in x 8in). A pan placed underneath the crib containing 170g (6oz) of Excelsior and 0.9oz (25ml) of heptane was used as the ignition source for the crib. This scenario was conducted in CIC, where the wood crib was located 0.6m (2ft) above the deck.

4.1.13 Scenario 13 – Trash Can Fire next to an Office Chair

A 6 L (1.6 gal) metal trashcan was filled with 5 full sheets of newspaper and pieces of cardboard totalling 0.8m^2 (8ft^2), arranged in the same way as described in Scenario 3. This was placed next to a commercial office chair consisting of a polyurethane foam cushion with upholstery (computer desk type chair with height adjustment and swivel options) in CIC. The trashcan was placed so that the edge of the chair seat and the trashcan were in line, with the back of the chair and trashcan also in line. The newspaper was ignited with a butane lighter. During this test, the flame of the trash can fire impinged on the edge of the chair seat and edge of the chair back, causing vigorous burning of the upholstery and polyurethane foam cushion. Some melting and pooling of the polyurethane foam and other plastic in the office chair was also observed during this test.

4.1.14 Scenario 14 – Brief Wire Overheat

This source consisted of temporarily overheating a 24 AWG PVC wire energized at 28 amps, 20V for 30 seconds. This test was intended to represent a transient burn out of an electrical component. Though a transient event, the effluent from this source is the same as a case in which the event is the early stages of a longer, developing electrically energized cable fire. The wire was NORDCOM/CDT's RZ distributing frame wire, consisting of a single 0.7 mm (0.178 in.) diameter strand insulated with PVC to a radial thickness of 1.0 mm (0.041-in). The wire was wrapped around an inert strip of marinite board approximately 5ft (1.5m) above the deck. The wire was energized using a Kenwood model PD18-3AD regulated DC power supply and 10 awg stranded wire leads, 10.66-ft (3.25 m) long between the wire sample and the power supply. Two locations were used each time this scenario was conducted. At first, the wire source was located in the standard location in the Ops Office corner, and then a second wire was energized underneath the primary detector location (Location A).

4.2 Nuisance Scenarios

This section describes the various nuisance scenarios selected for testing in this program. A summary table of these scenarios is provided in Table 2. All of these scenarios were conducted in the Ops Office.

Table 2. Summary of nuisance scenarios.

Nuisance Scenario	*Description*	*Location*
N01	Arc Welding	Ops Office
N02	Cutting Steel with an Acetylene Torch	Ops Office
N03	Burning Popcorn	Ops Office
N04	Cigarette Smoke	Ops Office
N05	Normal Toasting	Ops Office
N06	Grinding Steel	Ops Office
N07	Burning Nylon Rope Ends	Ops Office

4.2.1 Scenario 1 – Arc Welding

Welding and other hot work are typical maintenance activities that can occur onboard a ship. Welding of steel was conducted in the compartment 0.6 m (2 ft) above the deck. The arc welding consisted of running a weld across a 0.6 cm (0.25 in.) thick steel plate using a 0.32 cm (0.125 in.) number 7018 rod and a constant current setting of 100A. A total of 12-13 rods were used during the 17-20 minute exposure time for each of the two welding scenarios conducted.

4.2.2 Scenario 2 – Steel Cutting

An oxy-acetylene torch was used to cut a 0.48 cm (0.189 in.) thick steel plate, 0.6 m (2 ft) above the deck. Cutting occurred in a continuous fashion by cutting off 5cm (2in) wide strips of steel from the plate. The cut strips varied in length as the plate was not a regular rectangle. In both tests where cutting was performed, it was essentially continuous for about 10 minutes in the first test and 5 minutes in the second test.

4.2.3 Scenario 3 – Burning Popcorn

A typical bag of microwave popcorn was cooked on high in an 850 W microwave oven (a Tappan Model TMT1046150) for 12 minutes. The bottom of the microwave was 4ft (1.2m) above the deck. By the end of the 12 minute period, the popcorn was a black mass of char.

4.2.4 Scenario 4 – Cigarette Smoke

Although smoking is prohibited inside Navy ships, it still remains a very plausible nuisance source. This test consisted of four people chain smoking cigarettes in the test compartment, where each person smoked 4 to 6 cigarettes (Camel Filters or Doral Menthols). The four people were allowed to wander and converse in the general area below the sensors. In the first smoking test, a total of 24 cigarettes were smoked in 24 minutes. Twenty minutes into this test, the smokers gathered under the detectors at location A to smoke their last cigarette. They also blew smoke directly at the sensors a couple of times. In a second test, a total of 16 cigarettes were smoked in 16 minutes. Similar to the first test, a couple of smokers rested under the sensors while smoking their last cigarette.

4.2.5 Scenario 5 – Normal Toasting

In this test, two four-slice toasters (Toastmaster Model D165, 120 V, 50-60 Hz, 1700W) were filled with white bread and set to "dark". Eight slices of bread were toasted resulting in very dark toast, however none of the slices were burnt in this test. The bottom of the toasters was 1.2m (4ft) above the deck.

4.2.6 Scenario 6 – Grinding Steel

A handheld grinder was used to grind rusty steel tubing in this test. The grinder used was a Black and Decker 4.5in Angle Grinder, Model 2750G, with a Norton General Purpose Mini Disc grinding pad that had a 11cm (4.5in) diameter and was 0.6cm (0.25in) thick. The grinding took place approximately 0.3m (2ft) above the deck. Grinding was conducted for 15 minutes, resulting in mainly steel sparks and rust dust.

4.2.7 Scenario 7 – Burning Nylon Rope Ends

Two 1m (3.5ft) lengths of 1.25cm (0.5in) diameter nylon rope were positioned vertically 0.3m (2ft) above the deck, and ignited with a butane lighter in this test. Ignition was difficult to maintain with this material, as the nylon would melt, drip, and sometimes drop flaming pieces of melted nylon. Reignition with the butane lighter was then necessary. Very little smoke was produced from the nylon.

4.3 Transition Sources

This section describes the various transition sources that were evaluated. The intent of these tests was to determine the ability of detectors to correctly classify those sources that begin as a nuisance and transition into a fire. A summary of these scenarios is given in Table 3. All of these tests were conducted in the Ops Office.

Table 3. Summary of Transition Sources

Transition Scenario	*Description*	*Location*
T01	Normal Toasting → Burning Toast	Ops Office
T02	Burning Nylon Rope → Trashcan Fire	Ops Office
T03	Arc Welding → Smoldering Trashbag	Ops Office
T04	Cutting Steel → Flaming Bedding Fire	Ops Office

4.3.1 Scenario 1 – Normal Toasting becoming Burning Toast

In this test, one four-slice toaster (Toastmaster Model D165, 120 V, 50-60 Hz, 1700W) was filled with four sclices of either white or potato bread and set to the "dark" setting. The toaster levers were depressed and clamped down to continue toasting beyond the time of normal "pop-up". The bottom of the toaster was 4ft (1.2m) above the deck. This source initially produced a small amount of light, white smoke. As the test continued, the toast became charred resulting in thick grey smoke issuing from the top of the toaster as a well defined plume. At the point in which the toast became black and unedible and the smoke production increased substantially, this source was reclassified as a fire source. Besides the increased smoke production, previous experience has shown that the toast/toasters can ignite causing a flaming fire during this stage of heating.

4.3.2 Scenario 2 – Burning Nylon Rope Ingiting Trashcan Contents

A 1m (3.5ft) lengths of 1.25cm (0.5in) nylon rope was ignited with a butane lighter. Once sustained ignition had been established on the rope, it was allowed to burn for approximately 5 minutes and then suspended over a trashcan. The trashcan was the same as described in Fire Scenario 3, with 5 full sheets of newspaper and 2 pieces of cardboard totalling $0.8m^2$ ($8ft^2$). An oily rag was not used in this scenario. The dripping of the burning nylon eventually caused ignition of the paper material in the trashcan.

4.3.3 Scenario 3 – Arc Welding Igniting a Plastic Trashbag

This test simulated the smoldering ignition of a plastic trashbag from welding work being performed nearby. The trashbag and its setup were the same as described in section 4.1.5, also containing typical waste items. The welding was performed as described in section 4.2.2, except that 12 rods were used over a 17 minute period. Once the welding was completed, the Calrod was placed under the trashbag and energized to 50% of capacity, using the variac. The bag smoked lightly for about 36 minutes and most of the smoke escaped from the bag through a 5cm

(2in) hole in the top of the bag. After the test, it was discovered that the Calrod was resting under a large chicken wing bone, which may have hampered increased smoldering.

4.3.4 Scenario 4 – Cutting Steel Igniting Bedding Material

This test simulated the flaming ignition of bedding material from hot-work being conducted nearby. The bedding was set up in the same exact manner described in previous tests using bedding materials. The cutting of steel was performed as described in section 4.2.3, except that cutting was conducted for 5 minutes. At the end of the steel cutting, the bedding material was ignited with a butane lighter. Sustained ignition proved to be difficult, so an 11.4cm (4.5in) pan with 70ml (2fl.oz) of heptane was placed behind the bedding material and ignited. Subsequent flaming ignition of the bedding materials occurred about 9 minutes later. The fire was extinguished about 2 minutes later.

4.4 Sensor Calibration Tests

Sensor calibration checks were performed at the beginning and the end of this test series for the carbon monoxide, oxygen, and hydrocarbon sensors. These sensors were tested using standard calibration gases with 50 ppm concentrations for both the carbon monoxide and ethylene (hydrocarbon) sensors, and 100% nitrogen for testing the oxygen sensor. The general procedure was to collect 5 minutes of background data and then to pass the calibration gas over the sensor at a rate of 300 to 500ml/min until the sensor reading stabilized.

In comparing the pre-testing calibration tests with the post-testing calibration tests, it is evident that the CO and O_2 sensors were generally stable, with little drift in the measurements. Table 4 summarizes the calibration experiments. The only potential drift occurred in the hydrocarbon and EWFD2B-CO sensors, which changed by +3.5ppm (ambient) and –6ppm respectively, from the pre-test to post-test calibration checks. The pre-testing calibration check of the hydrocarbon sensor was terminated before a stable reading was achieved because the gas sample container was depleted due to the long response time.

5.0 EXPERIMENTAL SETUP

5.1 Test Area and Closures

The test area for this series was FR 15 to 29 on the second deck (Figure 1). This test area consisted of three spaces. The forward space from FR15 to 22 was designated CIC, the starboard space from FR 22 to 27 was designated the Operations Office (Ops Office) and the surrounding space to the Ops Office was designated the Combat Systems Office. The Operations Office was the primary fire space. Most sources were located in the aft starboard corner of the Ops Office (source location 1). For several fire sources, which were generally larger (>100 kW) than those

Table 4. Summary of Sensor Calibration Tests.

	Pre-Testing Calibration			*Post-Testing Calibration*		
	Ambient Reading (ppm)	Stabilized Reading (ppm)	Reaction time (sec) [ambient to stabilized]	Ambient Reading (ppm)	Stabilized Reading (ppm)	Reaction time (sec) [ambient to stabilized]
EWFD1A – CO	-0.2	50.4	24	0.3	50.5	30
EWFD2A – CO	0	64	53	-0.2	64	60
EWFD1B – CO	0.1	50.4	56	0.3	50.5	54
EWFD2B – CO	-0.1	52	47	-0.5	46	47
Oxygen	21.3 (%)	0 (%)	36	21.3 (%)	0 (%)	49
Hydrocarbon	0.1	32 (not stabilized)	332	3.6	50.5	220

conducted in the Ops Office, the source location was in CIC at 2-20-1 (source location 2). This location was used so that the detectors were not exposed to high temperature gases and also provide data to assess detector spacing issues. Additionally, some of the nuisance sources were moved to a position underneath the detectors between the EWFD prototypes and Simplex detectors at location A if no alarms were recorded during the initial part of the test.

All perimeter doors and scuttles were closed to the test area during each test. The following closure plan was used to allow ventilation between compartments in the test area:

Fittings that were open:

1.	Doorway	2-22-1
2.	QAWTD	2-22-2
3.	QAWTD	2-26-0
4.	QAWTD	2-22-4
5.	WTD	2-20-2

Fittings that were closed:

1.	WTD	2-29-0
2.	QAWTD	2-26-2
3.	QAWTH	2-15-2
4.	QAWTH	2-15-1
5.	QAWTD	2-17-1
6.	QAWTD	2-21-1
7.	QAWTS	2-24-1

The ventilation in the space consisted of the Total Protection Exhaust System (TPES) drawing air through two exhaust ducts located within the Engineering Office, which is located between FR20 and FR22 on the port side of CIC. Supply air was provided through the leakage in the test area. The measured air flow rates at the opening of the two TPES ducts were 680 cfm and 710 cfm. The combined air flow rate of 1390 cfm effectively produces four air changes per hour in the total test area, which has a volume of approximately 567 m^3 (20,000 ft^3). This ventilation is representative of the 4 to 5 air changes per hour that is typically found on Navy ships [6].

5.2 Prototype Fire Detection System

Two prototype fire detection system configurations were evaluated. The detection system consisted of a group of sensors, a data acquisition system and a desktop computer used to implement the alarm algorithm (PNN) processing, data storage, and display. The details of the two prototype detectors and the data acquisition system are discussed in the following sections.

5.2.1 Sensors

The primary differences in the two prototype detectors was the group of sensors, and consequently, the probabilistic neural network (PNN) alarm algorithm, which was based on the sensors used [1]. Table 5 shows the sensor details for each of the prototypes. The sensors of a detector were mounted together as a single assembly, as shown in Figure 2. The sensors were mounted on a steel chassis that encased a power supply and much of the wiring. The chassis was also designed with mounting flanges to fasten it to the overhead. Four System Sensor ionization and four photoelectric detectors were used in the four prototypes. System Sensor provided correlations (based on UL 268 smoke box data) to convert the sensor outputs to engineering units. The conversions used are listed in Table 6. The ionization ΔMIC value was converted to percent obscuration per meter using a second general correlation from System Sensor data obtained from UL 268 smoke box tests.

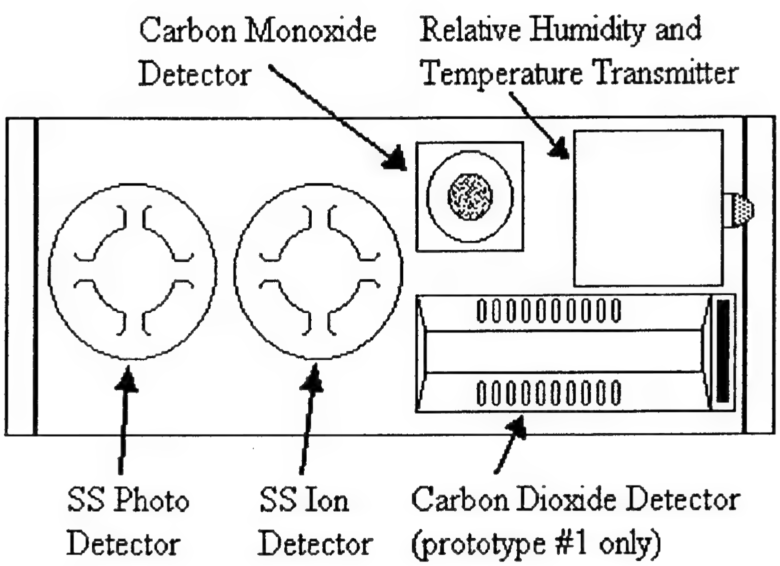

Figure 2. Physical layout of sensors when mounted on chassis.

Table 5. Details of prototype fire detectors.

No.	*Species*	*Sensor Range*	*Resolution*	*Instrument Model No.*	*Manufacturer*
	Prototype No. 1 (EWFD1)				
1	Ionization smoke detector	d MIC ~ 40		1251 with base no. B501	System Sensor
2	Photoelectric smoke detector	0.052-12.5 %/m (0.016 - 4 %/ft)	0.052 %/m (0.016 %/ft)	2251 with base no. B501	System Sensor
3	Carbon monoxide ($CO_{50\ ppm}$)	0-50 ppm	0.5 ppm	TB7E-1A	City Technology
4	Relative humidity (RH)	3-95%	$\pm$2% RH accuracy	HX93V transmitter	Omega
5	Carbon dioxide (CO_2)	0-5000 ppm	Accuracy= greater of $\pm$5% of reading or $\pm$100 ppm	2001V	Telaire/Engelhard
	Prototype No. 2 (EWFD2)				
1	Ionization smoke detector	d MIC ~ 40		1251 with base no. B501	System Sensor
2	Photoelectric smoke detector	0.052-12.5 %/m (0.016 - 4 %/ft)	0.052 %/m (0.016 %/ft)	2251 with base no. B501	System Sensor
3	Carbon monoxide ($CO_{100\ ppm}$)	0-100 ppm	0.5 ppm	TB7F-1A	City Technology
4	Relative humidity (RH)	3-95%	$\pm$2% RH accuracy	HX93C transmitter	Omega
5	Temperature (Temp Omega)	-20C to 75C	$\pm$0.6°C accuracy	HX93C transmitter (RTD)	Omega

Table 6. Conversions of System Sensor detectors used in the prototypes

Detector Type	Prototype	*Conversion*
Ionization 1	1A	$\Delta MIC = \Delta V * 45$
Photoelectric 1	1A	$\%/ft = \Delta V * 2.7$
Ionization 2	1B	$\Delta MIC = \Delta V * 50$
Photoelectric 2	1B	$\%/ft = \Delta V * 2.5$
Ionization 3	2B	$\Delta MIC = \Delta V * 50$
Photoelectric 3	2B	$\%/ft = \Delta V * 2.4$
Ionization 4	2A	$\Delta MIC = \Delta V * 47$
Photoelectric 4	2A	$\%/ft = \Delta V * 3.0$

5.2.2 Data Acquisition and Processing

Each sensor was hard-wired to the data acquisition system, which was located in the starboard side Node Room (see Figure 1). The data acquisition system consisted of National Instruments hardware (SCXI 1001 Chassis, SCXI 1100 modules, and SCXI 1303 Terminal Blocks) controlled via LabVIEW 5.1 full development software. The data acquisition system was operated using a Dual Pentium 200MHz PC computer running Windows NT (128MB RAM). The LabVIEW software was used to develop a data acquisition controller that could acquire data and execute the PNN alarm algorithm in real time, save the data, display the data, and send the data to a computer in the Control Room via the fiber optic Ethernet. The PNN software was written using MATLAB (which can interface with LabVIEW) and the data was transmitted to the Control Room using the software package DataSocket (provided with LabVIEW). During tests, the data acquisition/processing system was synchronized in time with the COTS Simplex smoke detection system currently installed on the ship. A more detailed explanation of the data acquisition system can be found in Appendix A.

5.2.3 Detector Locations

The two prototype detectors (Table 5) were co-located with the COTS system (Simplex photo and ion) in the center of the Ops Office at Detector Location A. Figure 3 shows the locations of the detectors in the test area. A second set of the two prototype detectors were also located in the overhead at Detector Location B along with a second set of Simplex photo and ion detectors (part of the COTS system). This second set of detectors provided additional information on detector sensitivity with respect to distance between the source and the detector. The "extra sensors" indicated in the figure are described in the next section. The exact locations of the detector groups are indicated in Table 7.

Table 7. Location of detectors in ops office.

Detector Group	*Distance Port of Source Location 1 (m [ft])*	*Distance Forward of Source Location 1 (m [ft])*	*Radial Distance from Source Location 1 (m [ft])*
Simplex COTS at Location A	2.5 [8.3]	2.4 [7.8]	3.5 [11.3]
EWFD Detectors at Location A	3.2 [10.5]	2.4 [7.8]	4.0 [13.1]
Simplex COTS at Location B	4.4 [14.3]	3.7 [12.1]	5.7 [18.7]
EWFD Detectors at Location B	5.1 [16.8]	3.5 [11.6]	6.2 [20.5]
Extra Sensors	3.7 [12.0]	2.4 [7.8]	4.4 [14.4]

Notes:

- Source location 1 was assumed to be approximately two feet from both the aft and starboard bulkheads.
- All locations represent the point that was midway between each group of detectors.

5.3 Additional Instrumentation

The performance of the prototype fire detectors was compared to the performance of the conventional ionization and photoelectric smoke detectors currently installed onboard ship (COTS Simplex system). The shipboard system consisted of Simplex ionization detectors (Model 4098-9717) and Simplex photoelectric detectors (Model 4098-9714) monitored with a single alarm panel (Simplex Model 4020). This fire alarm system provided time of alarm data for the exposed detectors. Additionally, the alarm verification feature was enabled for these detectors so that performance could be evaluated based on the goal of minimizing nuisance alarms. The alarm sensitivity of these detectors was set to 8%/m (2.5%/ft) for photoelectric and 4.2%/m (1.3%/ft) for ionization, which have been the settings of operation over the past months.

Three thermocouples were positioned in the Ops Office to monitor overhead temperatures. Thermocouples were mounted at each of the Detector Locations (A & B), as noted on Figure 1, to measure the air temperature near the prototypes. The third thermocouple was mounted on the overhead to monitor the deck temperature under the Emergency Generator and switchboard.

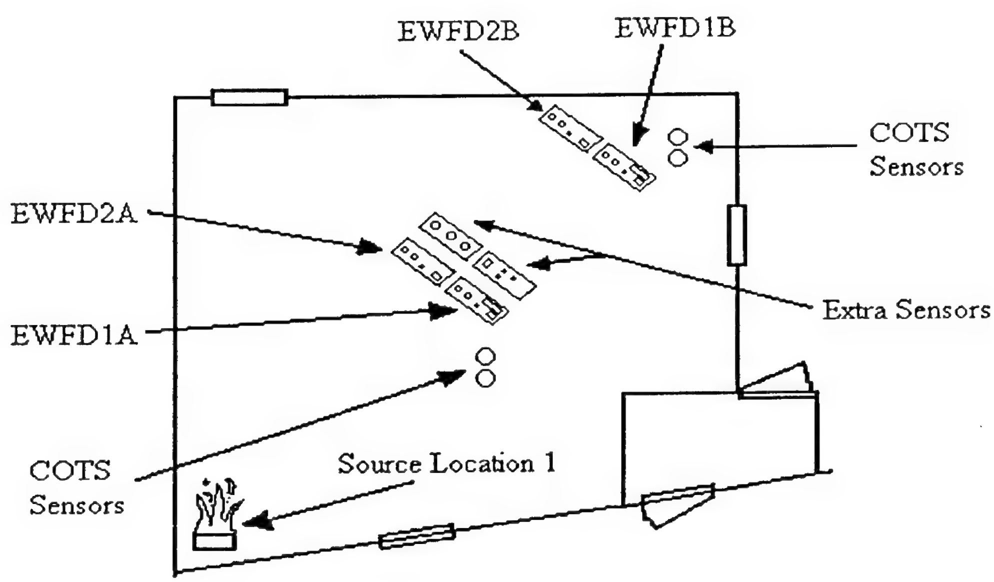

Figure 3. Locations of detectors in the operations office.

Additional sensors were included for data collection and future algorithm development. Other sensors included oxygen, hydrogen sulfide, nitric oxide, hydrocarbon, residential ionization smoke detector and the same model residential ionization smoke detector with the cover and bug screen removed. The hydrocarbon sensor and standard residential smoke detector were mounted on the board with the SAM Detector™. The remainder of the sensors were located on a chassis similar to the prototype chassis and mounted as the forward set of "extra sensors" indicated in Figure 3. Table 8 summarizes the additional sensors used in these tests.

Two video cameras were installed as shown in Figure 1. This figure indicates the setup used for the majority of the tests. The cameras in the Ops Office were positioned to view the smoke development and movement in the overhead near the sensors and to view the fire/nuisance source. For tests conducted in CIC, one camera monitored the smoke movement near the sensors, and the other camera was positioned to monitor the fire source in CIC.

Table 8. Additional sensors to be mounted with prototype detectors.

No.	*Species*	*Sensor Range*	*Resolution*	*Instrument Model No.*	*Manufacturer*
1	Oxygen (O_2)	0-25%	0.1% O_2	6C	City Technology
2	Hydrogen sulfide (H_2S)	0-5 ppm	0.1 ppm	TC4A-1A	City Technology
3	Nitric oxide (NO)	0-20 ppm	0.5 ppm	TF3C-1A	City Technology
4	C_1 to C_6 Hydrocarbons (Ethylene) (will be calibrated with ethylene)	0-50 ppm	$\pm$2.5 ppm	SM95-S2 with generalhydrocarbons solid state sensor	International Sensor Technology
5	Residential ionization smoke detector with standard housing	No applicable engineering units		83R	First Alert
6	Residential ionization smoke detector without housing or bug screen	No applicable engineering units		83R	First Alert
7	SamDetect ™ A multi-sensor fire detector	various	(confidential)	SamDetect B1	RST, DaimlerChrysler

6.0 PROCEDURE AND SAFETY

At the beginning of each day, the daily checklist was completed (Appendix B). Prior to each test, the test area was cleared of all personnel not involved with testing from the main deck to the third deck, frames 29 forward. All designated hatches and doors were closed, and the prescribed ventilation was set. After completion of these tasks, test personnel were positioned in the appropriate locations. When the fuel package was prepared and the safety team in position, data collection and videos were initiated. Following approximately 5 minutes of background data, either the fire was ignited, the "nuisance activity" initiated or the Calrod energized for the smoldering fire scenarios. During the test, SHADWELL personnel made visual observations, and event data was collected for the duration of the test. After the fire/nuisance activity was complete or all of the compartment's sensors had alarmed, the compartment was ventilated by opening the F-stop at 2-15-1 and WTD 2-29-0 and turning on the E1-15-1 fan. Data collection continued for 10 additional minutes to assess the recovery of the sensors following the event. Once the safety team deemed the test area safe for personnel without breathing protection, the test area was prepared for the next test. This preparation included any cleanup of the test area, equipment setup for the next test, and verification of instruments.

7.0 TEST SUMMARY

This section provides a summary of all the tests conducted. Table 9 presents the pertinent test times and ambient conditions from this test series. The column "transition or source move time" indicates the test time when a nuisance source became a fire source, or when a nuisance source was moved under the detectors and re-initiated. Pertinent details about this change (if present) are explained in the comments. Tables 10 to 13 show the results from individual detectors, showing alarm times, classifications, and sensor readings at alarm for the prototype detectors. In these tables, "DNA" means "did not alarm", "NDT" means "no data taken" for that particular test, and "B5V" means "beyond five volts". This last items refer to the output of the residential ionization detectors, which was in volts. An alarm condition for the residential detectors was noted when they recorded a one volt increase from the average background reading. The data acquisition system was limited in measurement to plus or minus five volts, and there were a few tests where the average background reading from the residential ion detector was greater than four volts. This condition resulted in the inability to measure the one volt difference for alarm condition. Voltage dividers were subsequently added to solve this problem. In Tables 10 and 11, some of the prototype "Alarm Times" are listed with additional information in the form of "(P=0.###)"; these entries are present for cases in which the EWFD prototype did not alarm. In these alternate entries, the information shown is the time when the peak alarm *probability* was reached and the associated time and sensor readings. Table 14 lists all the performed tests, indicating the specific scenarios that were used for each test where applicable. Discussion of the results as they apply to the objectives of this test series are presented in Section 8.

Table 9. Time and ambient conditions of test scenarios.

Test	Fire type	Brief Description	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Transition or Source move time (secs after initiation)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
001	fire, flaming	Heptane	2/10/00	15:25:28	15:31:40	372	-	15:50:42	1142	61	83	20	192	Alarm probability level for EWFD prototypes was changed from 0.85 to 0.75 about 3 minutes after ignition. Real time alarms were not working during this test. Alarm times were post-processed.
002	fire, flaming	Pipe insulation and fuel oil	2/10/00	16:50:13	16:57:08	415	-	17:09:40	752	59	94	15	152	Hydrocarbon sensor indicated significant rise before flame was visible. Real time alarms were not working during this test. Alarm times were post-processed.
003	fire, flaming	Oily rag, newspaper, cardboard in sm. Trashcan	2/11/00	10:47:25	10:52:49	324	-	10:59:00	371	61	95	13	145	
004	nuisance / fire	Burning toast	2/11/00	11:40:03	11:45:30	327	338	11:55:00	570	62	94	12	140	4 slices of white bread. Transition from nuisance to fire source was at approximately 338 seconds after toasting started (11:51:08). Indicated by heavier smoke plume.
005	fire, smold-ering	Smoldering trash bag	2/11/00	12:56:32	13:01:50	318	-	13:52:20	3030	62	95	12	149	A lot of moisture in the trash bag. Calrod was increased to 100% power 2502 seconds after calrod initiation (13:43:32)
006	nuisance	Cigarette smoking	2/11/00	14:15:36	14:21:06	330	1240	14:45:18	1454	65	85	7	169	At 1240 seconds after smoking started, smokers moved directly under sensors EWFD1A and EWFD2A. Alarms recorded after this time were not considered failures. (Smokers also blew directly onto sensors after this time)
007	fire, flaming	Flaming trashbag, TODCO wallboard	2/14/00	9:05:29	9:11:13	344	-	9:19:40	507	69	87	13	259	
008	fire, flaming	Heptane	2/14/00	9:53:50	9:59:45	355	-	10:15:45	960	69	81	12	278	

Table 9. Time and ambient conditions of test scenarios. (continued)

Test	Fire type	Brief Description	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Transition or Source move time (secs after initiation)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions: Temperature (°F)	Ambient Conditions: Relative Humidity (%)	Ambient Conditions: Wind Speed (mph)	Ambient Conditions: Wind Direction (degrees)	Test Comments
009	nuisance	Burning popcorn	2/14/00	10:46:43	10:51:58	315	-	11:05:24	806	70	76	14	266	EWFD 1A was only briefly in alarm (30 seconds) EWFD 2A was in alarm for 90 seconds
010	fire, flaming	Electrical cable and pipe insulation	2/14/00	12:46:57	12:52:23	326	-	13:00:24	481	74	39	14	287	
011	fire, smold-ering	Smoldering electrical cable	2/14/00	13:59:36	14:05:06	330	-	14:36:32	1886	74	31	18	289	
012	nuisance	Arc welding	2/14/00	15:52:13	15:57:23	310	785	16:18:12	1249	77	30	9	267	Welding location moved from corner of Ops Office to under "A" detectors at 785 seconds after welding began (16:10:28)
013	fire, flaming	Flaming bedding material	2/15/00	11:46:43	11:52:18	335	-	12:03:56	698	64	52	3	254	
014	fire, flaming	Oily rag, newspaper, cardboard in sm. Trashcan	2/15/00	13:02:06	13:07:37	331	-	13:20:40	783	69	50	6	160	
015	nuisance	Normal toasting	2/15/00	14:47:23	14:53:30	367	409	15:10:00	990	64	77	6	162	After toasters were done in the corner, they were moved under "A" detectors. New toasting in this location began 409 seconds after the initial toasting was started. (15:00:21)
016	fire, flaming	Small wood crib	2/15/00	15:35:13	15:41:22	369	-	16:02:05	1243	66	78	12	178	
017	fire, flaming	Trashcan and office chair	2/15/00	16:54:26	16:56:53	207	-	17:06:20	567	66	76	8	176	
018	nuisance	Steel Cutting	2/16/00	8:23:38	8:28:57	319	-	8:38:35	545	63	99	2	1	

Table 9. Time and ambient conditions of test scenarios. (continued)

Test	Fire type	Brief Description	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Transition or Source move time (secs after initiation)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
019	fire, smold-ering	Smoldering bedding material	2/16/00	8:55:41	9:01:01	320	-	9:21:10	1209	62	100	5	15	Variac set to 100% at 314 seconds after initiation. (9:06:15) Variac set to 75% at 764 seconds after initiation. (9:13:45)
020	fire, smold-ering	Printed wire circuit board	2/16/00	9:40:29	9:45:42	313	-	10:06:42	1260	64	100	3	313	
021	fire, smold-ering	Brief wire overheat	2/16/00	10:32:52	10:40:52	480	218	10:45:40	288	68	91	4	32	After first wire was done, it was moved to under "A" detectors and applied power 218 seconds after the first power up. (10:44:14)
022	fire, smold-ering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	2/16/00	11:11:19	11:16:30	311	-	11:33:05	995	71	88	6	68	
023	fire, flaming	Pipe insulation and fuel oil	2/16/00	12:38:52	12:44:45	353	-	12:48:53	248	70	96	7	125	
024	nuisance	Nylon rope	2/16/00	13:04:30	13:11:00	390	-	13:27:20	990	69	96	7	130	
025	nuisance/ fire	Nylon rope into sm. Trashcan	2/16/00	13:50:38	13:58:25	467	455	14:10:10	705	68	99	7	132	Time of ignition refers to the second ignition of the rope in this case. The transition to a fire occurred at 455 seconds after ignition (14:06:00) Detectors that alarmed before this time, or did not alarm after this time were considered failures.
026	fire, smold-ering	Smoldering trash bag	2/16/00	14:27:02	14:32:15	313	-	14:37:00	285	68	99	10	147	
027	nuisance	Burning popcorn	2/16/00	15:16:02	15:21:16	314	-	15:32:31	675	68	99	11	146	
028	nuisance	Steel grinding	2/17/00	8:41:11	8:47:06	355	634	9:02:48	950	63	99	5	153	Grinding location moved from corner to under "A" detectors 634 seconds after grinding began (8:57:40). A lot of rust
029	fire,	Smoldering	2/17/00	9:49:49	9:55:09	320	-	10:16:40	1291	63	100	5	148	

Table 9. Time and ambient conditions of test scenarios. (continued)

Test	Fire type	Brief Description	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Transition or Source move time (secs after initiation)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions: Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	Test Comments
	smold-ering	bedding material												
030	nuisance / fire	Burning toast	2/17/00	10:56:13	11:01:50	337	258	11:11:46	606	64	99	4	133	4 slices of potato bread. Transition from nuisance to fire source was at approximately 268 seconds after toasting started (11:05:58). Indicated by visible smoke plume from
031	fire, flaming	Pipe insulation and heptane	2/17/00	11:37:34	11:39:30	416	-	11:44:30	240	64	100	5	110	SAM Detector had not come out of alarm from previous test, when this was started.
032	nuisance	Cigarette smoking	2/17/00	12:36:35	12:42:04	329	626	13:03:30	1286	64	100	7	128	SAM Detector was going in and out of alarm as this test was beginning. At 626 seconds after smoking started, 1 person blew smoke on the "A" prototype detectors and then the "A" COTS sensors. Alarms recorded after this time were not considered failures.
033	fire, smold-ering	Printed wire circuit board	2/17/00	13:18:26	13:24:41	375	-	13:48:45	1444	66	100	8	113	
034	fire, smold-ering	Brief wire overheat	2/17/00	14:05:44	14:11:04	320	193	14:17:54	410	65	100	9	183	Second wire overheated under "A" detectors starting at 193 seconds after the first wire overheat (14:14:17).
035	fire, smold-ering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	2/17/00	14:31:02	14:36:19	317	-	14:46:00	581	65	100	7	167	
036	nuisance / fire	Arc welding, smoldering plastic trash bag	2/18/00	8:07:52	8:13:21	329	1069	9:08:45	3324	65	99	6	150	Trashbag placed on Calrod, and Calrod energized at 1069 seconds after welding started. (8:31:10) If a detector alarmed before this time, it was considered a failure. If the alarm was recorded after this time, it was considered a success.

Table 9. Time and ambient conditions of test scenarios. (continued)

Test	Fire type	Brief Description	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Transition or Source move time (secs after initiation)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
037	nuisance / fire	Steel cutting, flaming bedding material	2/18/00	9:39:28	9:45:01	333	745	10:10:00	1499	68	99	16	138	Cutting was conducted for 316 seconds (until 9:50:17). The bedding was then ignited with a butane lighter. However, the bedding didn't sustain ignition, so a small pool of heptane was ignited behind the sample 745 seconds after cutting was started (9:57:26). If a detector alarmed before this time, it was considered a failure. If the alarm was recorded after this time, it was considered a success.

Table 10. Summary of alarm times and sensor values for prototype detectors EWFD 1A and EWFD 2A.

Test	Fire type	Brief Description	EWFD 1A Alarm Time (sec after initiation)	EWFD 1A Ion Level (□MIC)	EWFD 1A Photo Level (%/ft)	EWFD 1A CO (ppm)	EWFD 1A Relative Humidity (%)	EWFD 1A CO_2 (ppm)	EWFD 1A Test Phase @ Alarm	EWFD 1A Correct Classification?	EWFD 2A Alarm Time (sec after initiation)	EWFD 2A Ion Level (□MIC)	EWFD 2A Photo Level (%/ft)	EWFD 2A CO (ppm)	EWFD 2A RH (%)	EWFD 2A Temp (°C)	EWFD 2A Test Phase @ Alarm	EWFD 2A Correct Classification?
001	fire, flaming	Heptane	151	42.2	0.6	2.3	51.8	884	fire	Y	184	31.7	0.7	2.9	44.8	25.8	fire	Y
002	fire, flaming	Pipe insulation and fuel oil	360	25.8	2.0	9.9	56.8	910	fire	Y	320	23.7	1.3	8.6	50.5	24.7	fire	Y
003	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	86	87.0	0.5	22.2	75.9	779	fire	Y	70	42.4	0.7	30.0	62.5	24.7	fire	Y
004	nuisance / fire	Burning toast	453	37.6	5.1	13.2	64.2	576	fire	Y	449	30.2	4.5	13.8	53.9	25.5	fire	Y
005	fire, smoldering	Smoldering trash bag	2786	11.1	0.2	30.5	54.7	637	fire	Y	2014	7.2	0.9	21.4	50.8	25.8	fire	Y
006	nuisance	Cigarette smoking	1322	12.6	0.7	31.0	57.1	772	nuisance	Y	1274	14.6	0.8	21.9	50.6	25.9	nuisance	Y
007	fire, flaming	Flaming trashbag, TODCO wallboard	168	7.1	0.1	38.2	65.5	612	fire	Y	179	24.9	2.2	48.7	51.9	29.1	fire	Y
008	fire, flaming	Heptane	135	34.3	0.5	2.0	44.5	758	fire	Y	223	35.2	0.8	3.2	43.5	30.8	fire	Y
009	nuisance	Burning popcorn	371	-1.3	0.0	15.5	48.8	631	nuisance	N	391	0.3	0.8	13.4	42.6	29.7	nuisance	N
010	fire, flaming	Electrical cable and pipe insulation	135	24.7	0.1	12.1	43.4	803	fire	Y	139	29.1	0.1	16.1	34.1	28.0	fire	Y
011	fire, smoldering	Smoldering electrical cable	2530 (P=0.717)	-5.6	0.0	-0.4	23.6	539.8	-	N	1972 (P=0.102)	-0.4	0.1	-1.3	22.0	29.3	-	N
012	nuisance	Arc welding	877	36.0	1.1	8.1	32.4	685	nuisance	N	880	34.7	2.1	8.6	24.4	29.9	nuisance	N

Table 10. Summary of alarm times and sensor values for prototype detectors EWFD 1A and EWFD 2A. (continued)

Test	Fire type	Brief Description	EWFD 1A								EWFD 2A							
			Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	RH (%)	Temp (°C)	Test Phase @ Alarm	Correct Classification?
013	fire, flaming	Flaming bedding material	70	22.2	0.6	28.9	44.9	767	fire	Y	58	24.9	1.1	23.8	28.1	29.2	fire	Y
014	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	69	39.5	0.1	10.3	40.5	786	fire	Y	71	31.9	0.3	13.7	38.8	28.3	fire	Y
015	nuisance	Normal toasting	571 (P=0.672)	33.9	0.0	-0.5	48.6	766.4	-	Y	559 (P=0.615)	22.0	0.1	-1.5	44.4	28.4	-	Y
016	fire, flaming	Small wood crib	157	4.2	0.1	30.9	52.7	747	fire	Y	146	2.0	0.0	22.5	41.8	28.2	fire	Y
017	fire, flaming	Trashcan and office chair	387	11.9	0.2	23.7	52.9	1189	fire	Y	361	16.4	0.1	19.7	43.3	28.3	fire	Y
018	nuisance	Steel Cutting	95	3.1	0.0	20.0	49.7	720	nuisance	N	99	6.0	0.1	17.8	43.3	29.9	nuisance	N
019	fire, smoldering	Smoldering bedding material	1027	11.9	0.5	21.3	54.4	674	fire	Y	454	0.4	0.8	9.6	48.3	28.2	fire	Y
020	fire, smoldering	Printed wire circuit board	1106 (P=0.187)	3.8	1.3	2.9	44.3	642.1	-	N	911 (P=0.198)	3.2	1.4	2.1	48.5	28.2	-	N
021	fire, smoldering	Brief wire overheat	268	34.9	5.1	5.0	55.7	678	fire	Y	314 (P=0.528)	7.9	1.0	1.5	52.6	27.2	-	N
022	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	865	53.4	5.1	50.5	80.6	638	fire	Y	858	34.7	4.5	101.0	58.9	27.4	fire	Y
023	fire, flaming	Pipe insulation and fuel oil	90	6.8	1.4	20.5	60.7	655	fire	Y	88	16.4	2.5	26.2	56.7	27.9	fire	Y
024	nuisance	Nylon rope	837 (P=0.195)	6.9	0.1	3.0	60.6	818.3	-	Y	494 (P=0.195)	5.9	0.3	1.1	55.5	28.3	-	Y

Table 10. Summary of alarm times and sensor values for prototype detectors EWFD 1A and EWFD 2A. (continued)

Test	Fire type	Brief Description	EWFD 1A								EWFD 2A							
			Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	RH (%)	Temp (°C)	Test Phase @ Alarm	Correct Classification?
025	Nuisance / fire	Nylon rope into sm. Trashcan	534	24.8	0.4	15.9	65.8	800	fire	Y	540	31.0	0.3	17.9	58.1	28.8	fire	Y
026	fire, smoldering	Smoldering trash bag	197	38.8	1.3	32.8	67.4	571	fire	Y	200	36.7	2.5	48.0	59.5	28.5	fire	Y
027	nuisance	Burning popcorn	292 (P=0.964)	3.7	0.0	13.2	64.4	575.2	-	Y	220	0.6	0.0	-1.5	57.8	28.5	nuisance	N
028	nuisance	Steel grinding	1543 (P=0.116)	-2.1	0.0	-0.4	66.7	550.7	-	Y	956 (P=0.121)	6.8	0.5	0.8	55.8	27.6	-	Y
029	fire, smoldering	Smoldering bedding material	1296	13.0	5.1	13.6	61.4	598	vent	N	1054	3.5	3.3	10.9	55.4	27.8	fire	Y
030	nuisance / fire	Burning toast	434	49.4	5.2	18.7	60.9	600	fire	Y	434	33.6	4.5	20.0	62.0	27.0	fire	Y
031	fire, flaming	Pipe insulation and heptane	97	23.3	2.7	28.3	69.4	682	fire	Y	88	25.3	3.9	31.1	63.1	26.3	fire	Y
032	nuisance	Cigarette smoking	1182 (P=0.226)	7.8	0.4	5.9	61.9	772.2	-	Y	62 (P=0.313)	1.7	0.0	-0.7	64.2	25.8	-	Y
033	fire, smoldering	Printed wire circuit board	1307 (P=0.198)	3.8	1.8	2.8	69.9	556.4	-	N	35 (P=0.461)	0.3	-0.1	-1.2	62.2	26.5	-	N
034	fire, smoldering	Brief wire overheat	260	36.2	1.0	45.2	77.0	618	nuisance	N	269	5.2	0.0	19.6	60.9	26.7	nuisance	N
035	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	503	38.2	5.1	50.3	81.9	558	fire	Y	497	33.2	4.5	101.0	64.7	27.2	fire	Y
036	Nuisance / fire	Arc welding, smoldering plastic trash bag	2097 (P=0.194)	2.3	0.3	0.6	46.0	560.8	-	N	1124 (P=0.457)	16.7	2.1	5.6	45.7	31.2	-	N

Table 10. Summary of alarm times and sensor values for prototype detectors EWFD 1A and EWFD 2A. (continued)

Test	Fire type	Brief Description	EWFD 1A								EWFD 2A							
			Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	RH (%)	Temp (°C)	Test Phase @ Alarm	Correct Classification?
037	Nuisance fire	/ Steel cutting, flaming bedding material	58	1.7	0.0	19.0	53.0	593	nuisance	N	52	8.5	0.1	13.6	50.5	29.7	nuisance	N

Table 11. Summary of alarm times and sensor values for prototype detectors EWFD 1B and EWFD 2B.

			EWFD 1B								EWFD 2B							
Test	Fire type	Brief Description	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	RH (%)	Temp (°C)	Test Phase @ Alarm	Correct Classification?
001	fire, flaming	Heptane	322	28.3	0.8	3.5	58.7	1083	fire	Y	118	16.5	0.4	0.8	48.0	20.8	fire	Y
002	fire, flaming	Pipe insulation and fuel oil	692	8.2	1.3	21.0	64.3	1337	fire	Y	285	3.6	0.5	2.3	47.0	25.6	fire	Y
003	fire, flaming	Oily rag, newspaper, cardboard in sm. Trashcan	88	21.1	0.5	25.4	84.0	570	fire	Y	68	30.2	0.8	14.3	47.1	32.7	fire	Y
004	nuisance / fire	Burning toast	561	25.8	4.8	46.6	73.8	554	fire	Y	187	0.4	0.0	-0.7	47.5	28.3	nuisance	N
005	fire, smoldering	Smoldering trash bag	3068 (P=0.223)	10.4	0.9	13.9	58.6	568	-	N	3237	3.8	0.1	2.2	48.2	25.5	vent	N
006	nuisance	Cigarette smoking	1322 (P=0.141)	2.8	0.3	5.5	62.5	625	-	Y	1701	-0.8	0.1	-0.6	48.4	25.2	vent	Y
007	fire, flaming	Flaming trashbag, TODCO wallboard	197	0.9	0.2	37.9	78.4	549	fire	Y	188	23.7	1.8	40.8	51.8	26.9	fire	Y
008	fire, flaming	Heptane	872	44.9	1.5	6.9	58.4	1816	fire	Y	188	29.9	0.6	1.8	53.2	20.0	fire	Y
009	nuisance	Burning popcorn	441 (P=0.588)	0.4	1.0	10.1	58.9	567	-	Y	441 (P=0.425)	-0.5	0.2	9.7	52.0	19.3	-	Y
010	fire, flaming	Electrical cable and pipe insulation	195	6.2	0.2	24.7	50.9	951	fire	Y	150	29.8	0.2	12.7	50.9	9.5	fire	Y
011	fire, smoldering	Smoldering electrical cable	2280 (P=0.127)	-2.7	0.0	-0.1	27.0	507	-	N	2506 (P=0.13)	-3.4	0.0	-1.2	51.3	-2.1	-	N
012	nuisance	Arc welding	1288 (P=0.125)	12.6	0.4	2.2	34.0	624	-	Y	1919 (P=0.056)	-0.4	-0.2	-1.3	51.4	-3.1	-	Y

Table 11. Summary of alarm times and sensor values for prototype detectors EWFD 1B and EWFD 2B. (continued)

Test	Fire type	Brief Description	EWFD 1B								EWFD 2B							
			Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	RH (%)	Temp (°C)	Test Phase @ Alarm	Correct Classification?
013	fire, flaming	Flaming bedding material	91	0.7	0.0	20.4	40.8	703	fire	Y	66	22.1	1.3	12.7	51.1	4.9	fire	Y
014	fire, flaming	Oily rag, newspaper, cardboard in sm. Trashcan	89	24.4	0.2	13.6	50.9	876	fire	Y	56	21.5	0.1	9.0	50.2	13.1	fire	Y
015	nuisance	Normal toasting	1076 (P=0.154)	1.1	0.0	-0.5	47.4	588	-	Y	452	2.3	0.0	-1.5	50.9	16.8	nuisance	N
016	fire, flaming	Small wood crib	117	0.5	0.1	22.6	54.1	625	fire	Y	124	2.3	0.2	19.9	50.5	18.0	fire	Y
017	fire, flaming	Trashcan and office chair	349	16.6	0.5	18.3	54.7	1086	fire	Y	351	20.3	0.4	17.8	50.9	19.1	fire	Y
018	Nuisance	Steel Cutting	321	18.7	0.0	23.1	57.9	758	nuisance	N	537	19.6	0.1	29.5	52.6	19.1	nuisance	N
019	fire, smoldering	Smoldering bedding material	1418 (P=0.102)	-0.3	0.1	0.6	60.0	531	-	N	1352	0.7	0.0	0.1	51.1	22.8	vent	N
020	fire, smoldering	Printed wire circuit board	1268 (P=0.111)	5.7	1.6	2.4	66.8	532	-	N	1377	1.3	0.2	-0.5	50.6	24.1	vent	N
021	fire, smoldering	Brief wire overheat	799 (P=0.111)	0.2	0.0	0.0	68.1	532	-	N	380	1.7	0.0	-0.7	49.6	28.1	vent	N
022	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	871	7.7	4.8	50.5	81.9	532	fire	Y	868	40.6	5.8	96.8	50.3	33.6	fire	Y
023	fire, flaming	Pipe insulation and fuel oil	129	0.3	1.2	15.9	72.3	550	fire	Y	109	7.1	0.8	15.6	50.4	32.2	fire	Y

Table 11. Summary of alarm times and sensor values for prototype detectors EWFD 1B and EWFD 2B. (continued)

Test	Fire type	Brief Description	EWFD 1B								EWFD 2B							
			Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	RH (%)	Temp (°C)	Test Phase @ Alarm	Correct Classification?
024	nuisance	Nylon rope	1412 (P=0.168)	0.0	0.0	-0.2	71.5	490	-	Y	1039	1.7	0.2	-0.9	51.2	29.2	vent	Y
025	Nuisance / fire	Nylon rope into sm. Trashcan	546	18.5	0.3	13.1	74.3	644	fire	Y	522	5.8	0.2	3.3	51.2	32.0	fire	Y
026	fire, smoldering	Smoldering trash bag	213	3.2	0.8	30.6	80.0	508	fire	Y	206	34.3	2.9	33.2	51.2	33.8	fire	Y
027	nuisance	Burning popcorn	469 (P=0.163)	1.9	0.8	1.0	72.3	508	-	Y	869	-0.9	0.1	-0.8	51.0	30.4	vent	Y
028	nuisance	Steel grinding	1576 (P=0.335)	-2.1	0.0	-0.1	74.5	471	-	Y	1097	2.4	0.1	-0.5	50.2	30.5	vent	Y
029	fire, smoldering	Smoldering bedding material	1179	5.1	2.9	5.3	68.6	508	fire	Y	1364	11.0	3.0	6.4	50.5	29.5	vent	N
030	nuisance / fire	Burning toast	531	17.6	4.8	35.7	86.4	532	fire	Y	292	0.2	0.0	-1.0	49.6	34.9	fire	Y
031	fire, flaming	Pipe insulation and heptane	126	1.4	0.0	26.2	84.9	550	fire	Y	94	5.7	4.1	16.1	48.9	36.8	fire	Y
032	nuisance	Cigarette smoking	1051 (P=0.486)	4.7	0.1	3.6	82.7	606	-	Y	1368	2.9	0.1	0.6	49.8	34.2	vent	Y
033	fire, smoldering	Printed wire circuit board	272 (P=0.42)	0.7	-0.1	-0.1	82.0	471	-	N	1543	2.1	0.2	0.0	50.2	32.4	vent	N
034	fire, smoldering	Brief wire overheat	759 (P=0.453)	-0.4	0.0	-0.1	77.8	469	-	N	525	1.7	0.0	-0.7	49.4	34.7	vent	N
035	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	514	2.5	4.8	50.3	101.4	472	fire	Y	509	41.8	5.8	101.0	50.0	39.2	fire	Y

Table 11. Summary of alarm times and sensor values for prototype detectors EWFD 1B and EWFD 2B. (continued)

Test	Fire type	Brief Description	EWFD 1B								EWFD 2B							
			Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	Relative Humidity (%)	CO_2 (ppm)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Ion Level (□MIC)	Photo Level (%/ft)	CO (ppm)	RH (%)	Temp (°C)	Test Phase @ Alarm	Correct Classification?
036	Nuisance fire	Arc welding, smoldering plastic trash bag	1251 (P=0.195)	16.4	1.5	3.2	70.3	587	-	N	3480	-0.2	0.2	-0.5	53.8	21.1	vent	N
037	Nuisance fire	Steel cutting, flaming bedding material	104	0.5	0.0	28.3	71.4	531	nuisance	N	77	0.7	0.1	15.8	52.6	25.4	nuisance	N

Table 12. Summary of alarm responses of the Simplex COTS detectors.

Test	Fire type	Brief Description	Simplex Photo (53) Location "A"			Simplex Ion (68) Location "A"			Simplex Photo (50) Location "B"			Simplex Ion (51) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
001	fire, flaming	Heptane	DNA	-	N	90	fire	Y	DNA	-	N	132	fire	Y
002	fire, flaming	Pipe insulation and fuel oil	653	fire	Y	389	fire	Y	407	fire	Y	486	fire	Y
003	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	343	fire	Y	54	fire	Y	350	fire	Y	70	fire	Y
004	nuisance / fire	Burning toast	469	fire	Y	450	fire	Y	487	fire	Y	450	fire	Y
005	fire, smoldering	Smoldering trash bag	2818	fire	Y	2900	fire	Y	DNA	-	N	DNA	-	N
006	nuisance	Cigarette smoking	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
007	fire, flaming	Flaming trashbag, TODCO wallboard	183	fire	Y	184	fire	Y	193	fire	Y	193	fire	Y
008	fire, flaming	Heptane	876	fire	Y	101	fire	Y	814	fire	Y	160	fire	Y
009	nuisance	Burning popcorn	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
010	fire, flaming	Electrical cable and pipe insulation	261	fire	Y	61	fire	Y	290	fire	Y	177	fire	Y
011	fire, smoldering	Smoldering electrical cable	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
012	nuisance	Arc welding	877	nuisance	N	820	nuisance	N	DNA	-	Y	1011	nuisance	N
013	fire, flaming	Flaming bedding material	DNA	-	N	60	fire	Y	DNA	-	N	160	fire	Y

Table 12. Summary of alarm responses of the Simplex COTS detectors. (continued)

Test	Fire type	Brief Description	Simplex Photo (53) Location "A"			Simplex Ion (68) Location "A"			Simplex Photo (50) Location "B"			Simplex Ion (51) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
014	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	676	fire	Y	39	fire	Y	684	fire	Y	55	fire	Y
015	nuisance	Normal toasting	DNA	-	Y	547	nuisance	N	DNA	-	Y	DNA	-	Y
016	fire, flaming	Small wood crib	1251	vent	N	858	fire	Y	276	fire	Y	121	fire	Y
017	fire, flaming	Trashcan and office chair	453	fire	Y	377	fire	Y	384	fire	Y	355	fire	Y
018	nuisance	Steel Cutting	DNA	-	Y	113	nuisance	N	DNA	-	Y	125	nuisance	N
019	fire, smoldering	Smoldering bedding material	530	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
020	fire, smoldering	Printed wire circuit board	918	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
021	fire, smoldering	Brief wire overheat	233	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
022	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	842	fire	Y	838	fire	Y	850	fire	Y	854	fire	Y
023	fire, flaming	Pipe insulation and fuel oil	162	fire	Y	86	fire	Y	167	fire	Y	DNA	-	N
024	nuisance	Nylon rope	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
025	Nuisance / fire	Nylon rope into sm. Trashcan	DNA	-	N	501	fire	Y	DNA	-	N	518	fire	Y
026	fire, smoldering	Smoldering trash bag	188	fire	Y	188	fire	Y	DNA	-	N	226	fire	Y
027	nuisance	Burning popcorn	432	nuisance	N	DNA	-	Y	674	nuisance	N	DNA	-	Y

Table 12. Summary of alarm responses of the Simplex COTS detectors. (continued)

Test	Fire type	Brief Description	Simplex Photo (53) Location "A"			Simplex Ion (68) Location "A"			Simplex Photo (50) Location "B"			Simplex Ion (51) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
028	nuisance	Steel grinding	DNA	-	Y	833	nuisance	N	DNA	-	Y	725	nuisance	N
029	fire, smoldering	Smoldering bedding material	822	fire	Y	DNA	-	N	964	fire	Y	DNA	-	N
030	nuisance / fire	Burning toast	454	fire	Y	458	fire	Y	479	fire	Y	454	fire	Y
031	fire, flaming	Pipe insulation and heptane	109	fire	Y	89	fire	Y	134	fire	Y	141	fire	Y
032	nuisance	Cigarette smoking	870	nuisance	N	DNA	-	Y	DNA	-	Y	DNA	-	Y
033	fire, smoldering	Printed wire circuit board	1026	fire	Y	DNA	-	N	1135	fire	Y	DNA	-	N
034	fire, smoldering	Brief wire overheat	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
035	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	496	fire	Y	493	fire	Y	500	fire	Y	505	fire	Y
036	Nuisance / fire	Arc welding, smoldering plastic trash bag	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
037	Nuisance / fire	Steel cutting, flaming bedding material	1419	fire	Y	57	nuisance	N	1373	fire	Y	143	nuisance	N

Table 13. Summary of alarm responses of the residential ionization detectors.

Test	Fire type	Brief Description	Residential Ion Chamber Only			Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
001	fire, flaming	Heptane	1012	fire	Y	B5V	-	-
002	fire, flaming	Pipe insulation and fuel oil	216	fire	Y	B5V	-	-
003	fire, flaming	Oily rag, newspaper, cardboard in sm. Trashcan	54	fire	Y	70	fire	Y
004	nuisance / fire	Burning toast	249	nuisance	N	B5V	-	-
005	fire, smoldering	Smoldering trash bag	2005	fire	Y	DNA	-	N
006	nuisance	Cigarette smoking	476	nuisance	N	B5V	-	-
007	fire, flaming	Flaming trashbag, TODCO wallboard	163	fire	Y	222	fire	Y
008	fire, flaming	Heptane	DNA	-	N	170	fire	Y
009	nuisance	Burning popcorn	336	nuisance	N	DNA	-	Y
010	fire, flaming	Electrical cable and pipe insulation	146	fire	Y	153	fire	Y
011	fire, smoldering	Smoldering electrical cable	DNA	-	N	DNA	-	N
012	nuisance	Arc welding	839	nuisance	N	826	nuisance	N
013	fire, flaming	Flaming bedding material	64	fire	Y	DNA	-	N

Table 13. Summary of alarm responses of the residental ionization detectors. (continued)

Test	Fire type	Brief Description	Residential Ion Chamber Only			Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?
014	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	98	fire	Y	148	fire	Y
015	nuisance	Normal toasting	423	nuisance	N	583	nuisance	N
016	fire, flaming	Small wood crib	157	fire	Y	DNA	-	N
017	fire, flaming	Trashcan and office chair	387	fire	Y	416	fire	Y
018	nuisance	Steel Cutting	120	nuisance	N	381	nuisance	N
019	fire, smoldering	Smoldering bedding material	481	fire	Y	DNA	-	N
020	fire, smoldering	Printed wire circuit board	DNA	-	N	DNA	-	N
021	fire, smoldering	Brief wire overheat	239	fire	Y	DNA	-	N
022	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	839	fire	Y	861	fire	Y
023	fire, flaming	Pipe insulation and fuel oil	80	fire	Y	261	vent	N
024	nuisance	Nylon rope	DNA	-	Y	DNA	-	Y
025	Nuisance / fire	Nylon rope into sm. Trashcan	546	fire	Y	586	fire	Y
026	fire, smoldering	Smoldering trash bag	184	fire	Y	206	fire	Y
027	nuisance	Burning popcorn	287	nuisance	N	DNA	-	Y
028	nuisance	Steel grinding	DNA	-	Y	DNA	-	Y

Table 13. Summary of alarm responses of the residental ionization detectors. (continued)

Test	Fire type	Brief Description	Residential Ion Chamber Only			Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Corrrect Classification?
029	fire, smoldering	Smoldering bedding material	849	fire	Y	DNA	-	N
030	nuisance / fire	Burning toast	202	nuisance	N	514	fire	Y
031	fire, flaming	Pipe insulation and heptane	72	fire	Y	222	fire	Y
032	nuisance	Cigarette smoking	1114	nuisance	N	DNA	-	Y
033	fire, smoldering	Printed wire circuit board	DNA	-	N	DNA	-	N
034	fire, smoldering	Brief wire overheat	232	fire	Y	DNA	-	N
035	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	489	fire	Y	511	fire	Y
036	Nuisance / fire	Arc welding, smoldering plastic trash bag	DNA	-	N	DNA	-	N
037	Nuisance / fire	Steel cutting, flaming bedding material	87	nuisance	N	1385	fire	Y

Table 14. Summary of tests conducted.

Test Designation	*Fire/Nuisance Scenario*	*Description*
Flaming Fire Sources		
EWFD 001	F01	Heptane
EWFD 002	F02	Pipe insulation and fuel oil
EWFD 003	F03	Oily rag, newspaper, cardboard in sm. Trashcan
EWFD 007	F06	Flaming trashbag, TODCO wallboard
EWFD 008	F01	Heptane
EWFD 010	F07	Electrical cable and pipe insulation
EWFD 013	F10	Flaming bedding material
EWFD 014	F03	Oily rag, newspaper, cardboard in sm. Trashcan
EWFD 016	F12	Small wood crib
EWFD 017	F13	Trashcan and office chair
EWFD 023	F02	Pipe insulation and fuel oil
EWFD 031	F02a	Pipe insulation and heptane
Smoldering Fire Sources		
EWFD 005	F05	Smoldering trash bag
EWFD 011	F08	Smoldering electrical cable
EWFD 019	F09	Smoldering bedding material
EWFD 020	F11	Printed wire circuit board
EWFD 021	N07	Brief wire overheat
EWFD 022	F04	Smoldering oily rag, newspaper, cardboard in sm. Trashcan
EWFD 026	F05	Smoldering trash bag
EWFD 029	F09	Smoldering bedding material
EWFD 033	F11	Printed wire circuit board
EWFD 034	N07	Brief wire overheat
EWFD 035	F04	Smoldering oily rag, newspaper, cardboard in sm. Trashcan

Table 14. Summary of tests conducted. (continued)

Test Designation	*Fire/Nuisance Scenario*	*Description*
Nuisance Sources		
EWFD 006	N04	Cigarette smoking
EWFD 009	N03	Burning popcorn
EWFD 012	N01	Arc welding
EWFD 015	N05	Normal toasting
EWFD 018	N02	Steel Cutting
EWFD 024	N07	Nylon rope
EWFD 027	N03	Burning popcorn
EWFD 028	N06	Steel grinding
EWFD 032	N04	Cigarette smoking
Transition Sources (nuisance to fire)		
EWFD 004	T01	Burning toast
EWFD 025	T02	Nylon rope into small Trashcan
EWFD 030	T01	Burning toast
EWFD 036	T03	Arc welding, smoldering plastic trash bag
EWFD 037	T04	Steel cutting, flaming bedding material
Other Tests		
Calib1	Carbon monoxide sensor calibration (EWFD1A, EWFD2B, EWFD1B, EWFD2B)	
Calib2	Continued carbon monoxide sensor calibration (EWFD2A, EWFD2B)	
Calib3	Hydrocarbon sensor calibration	
EWFD_bkgd	Background data between tests EWFD_016 and EWFD_017	
EWFD_bkgd2	Background data taken overnight	
Watermist	Background data taken during watermist fire test on another deck	

8.0 RESULTS AND DISCUSSION

The results from the test series as they apply to the objectives of the test series are discussed in this chapter. All reported results from the prototype sensors using the PNN alarm algorithm for detection times should be considered preliminary as the development of the algorithm has not yet been finalized. These results are included to indicate the strengths and weaknesses of the trial algorithms. The first part of this section discusses the implementation of the prototypes, then the response time performance of the prototype detectors, followed by classification performance of the prototype detectors, discussion of spacing effects, and finally results of the use of the fiber optic ethernet network.

8.1 Prototype with Real-Time Processing

Two prototype detectors were successfully designed, built, and tested in this test series. Each of these prototypes had an individually tailored, probabilistc neural network alarm algorithm that successfully operated in real-time with a data acquisition system to provide alarms. Only two problems were identified with the implementation of this experimental setup.

The first problem was with the sampling time in the data acquisition system. The target data sampling time for the experiments of this test series was one second. However, execution of the data acquisition system with the PNN limited the obtainable sampling time to two seconds. The problem observed was that the two second sampling time at the beginning of each test steadily became slower as the real-time processing continued. Typically, the data sampling time increased by approximately one second for every ten minutes of data collection. This problem was suspected to be a memory allocation error in the LabVIEW or MATLAB software, or in the software interface between these two programs when running in real-time. This problem is under investigation and several strategies are being pursued to maintain a constant sampling time during the tests in Test Series 2.

The other problem discovered was with the Omega relative humidity / temperature transmitter on prototype EWFD 2B. Examination of the data revealed that the trends of the relative humidity (RH) and temperature measurements appeared to be reversed, when compared to readings from prototype EWFD 2A. Post-test investigation of this issue revealed that the wiring in the Omega transmitter itself was reversed. The transmitter error resulted in the output signals from the RH and temperature sensors being converted in the data acquisition system via the correlations of the opposite sensor. Therefore, the output files include incorrect data for the EWFD2B RH and temperature measurements. The data will be corrected in the multivariate analysis phase of this program. The corrections will consist of back-calculating the data acquisition input voltage and then calculating the correct sensor value using the appropriate conversions as can be found in Appendix A. This error certaintly had an affect on the performance of the EWFD 2B alarm algorithm and will be corrected and assessed in the concurrent algorithm development phase of the program. Consequently, the results for the EWFD 2B prototype are suspect.

8.2 Average Response Time

As part of the post-test data investigation, the individual System Sensor photoelectric and ionization detectors on each prototype detector were evaluated for their detection times at various alarm levels (e.g., 1.63%/m, 4.2%/m, 8%/m). The average response times of the System Sensor detectors were compared to the Simplex smoke detectors, which were co-located in the test room. The response times were evaluated at alarm thresholds of 8%/m for photoelectric and 4.2%/m for ionization. The results are presented in Table 15. The average response times indicated in the table are based on "common alarms" in each category for each trio of detectors. Common alarms are simply defined as tests where the trio of detectors all alarmed. For example, the EWFD1B Photo, EWFD2B Photo and COTS 50 Photo recorded 12, 13, and 14 alarms respectively out of all of the 21 total fire tests. Out of all these alarms, there were only 11 tests where all three detectors alarmed. Therefore, the average response time for each detector is based on these 11 "common alarms." Because each trio of detectors is based on a different set of "common alarms" in each category, direct comparison of average response times between the detectors at different locations and between the types is not possible. Note that the shaded elements represent the "best" of each trio in each category (this notation applies to all the tables in this section). Additional information on the response time comparisons can be found in Appendix C.

Based on Table 15, the Simplex detectors responded faster on average than the System Sensor detectors that were part of the EWFD prototypes, with the exception of the System Sensor photoelectric detector at Location A. The most notable differences between the Simplex and the System Sensor detectors was observed at Location B, more so for the photoelectric sensors. The Simplex photoelectric detector was at least 100 seconds faster on average than the System Sensor detectors. However, the System Sensor detectors performed better on average in nuisance situations and tests where a nuisance transitioned into a fire. Note that three of the four System Sensor detectors at Location B were the only ones not to alarm during all 11 nuisance tests. It is also noted that these average values provide only a general indication of the differences in response time. This fact is evidenced by the large standard deviations associated with each average (see Appendix C).

The average response times of the prototype fire detectors when using the alarm algorithm were also compared to the Simplex smoke detectors. These results are presented in Table 16, and are subject to the same limitations and use of "common alarms" as explained for the previous results. These results show that prototype detector EWFD2 had the best overall average response times. EWFD2 responded 1 to 5 minutes faster than either the Simplex photo or ion smoke detectors at Location A. For smoldering fires, the response time between the prototype detectors and the Simplex smoke detectors were essentially the same. This may be due in part to the slower response of the System Sensor photoelectric detector used in the prototype. Again, it is important to note that the average response times of the detectors at the different locations cannot be directly compared because they are based on a different set of common alarms.

Table 15. Average response time of System Sensor detectors (as part of EWFD prototypes) compared to the Simplex detectors (times are in seconds after source initiation).

	"A" Loc. Ion Detectors			*"A" Loc. Photo Detectors*			*"B" Loc. Ion Detectors*			*"B" Loc. Photo Detectors*		
	EWFD 1A	*EWFD 2A*	*Simplex 68 I*	*EWFD 1A*	*EWFD 2A*	*Simplex 53 P*	*EWFD 1B*	*EWFD 2B*	*Simplex 51 I*	*EWFD 1B*	*EWFD 2B*	*Simplex 50 P*
All Fire Tests	263	283	230	558	478	480	431	299	273	556	538	436
Flaming Fire Tests	186	212	147	461	433	455	377	200	163	455	410	310
Smoldering Fire Tests	520	521	506	702	546	519	558	529	528	824	880	771
Nuisance Tests[A]	559	596	467	-	397	432	-	623	125	-	-	674
Transition Tests[B]	468	499	470	414	398	462	609	575	486	467	521	483

Notes: A – The "-" means that the detector did not record any alarms for nuisances.
B – The transition tests compasison only includes those where there were *correctly classified* common alarms. This was done so that an early incorrect alarm (during the nuisance phase) did not artificially reduce the average response time.

Table 16. Average response time of prototype detectors compared to the simplex detectors[A] (times are in seconds after source initiation).

	Detectors at Location A				*Detectors at Location B*			
	EWFD 1A	*EWFD 2A*	*Simplex Photo (53)*	*Simplex Ion (68)*	*EWFD 1B*	*EWFD 2B*	*Simplex Photo (50)*	*Simplex Ion (51)*
All Fire Tests	431	375	665	476	374	262	444	283
Flaming Fire Tests	168	169	497	224	303	167	392	195
Smoldering Fire Tests	1088	892	1086	1105	364	358	250	366
Transition Tests[B]	444	442	462	454	531	292	479	454

Notes:

A – This table does not include the nuisance alarms because there were not any common alarms from which to make a comparison.

B – The transition tests comparison only includes those where there were *correctly classified* common alarms. This was done so that an early incorrect alarm (during the nuisance phase) did not artificially reduce the average response time.

8.3 Classification of Test Sources

The prototype early warning fire detectors, Simplex detectors, the SAM Detector, and the residential detectors were all evaluated for their ability to correctly classify each test source as a fire or nuisance. For fire sources, correct classification for all detectors was achieved if the detector went into an alarm state at any time between ignition/initiation of the source and the start of post-test ventilation. For nuisance sources, correct classification for all detectors was achieved if the detector remained out of an alarm state for the time between the initiation of the nuisance source and the start of post-test ventilation. For transition tests (nuisance into fire), correct classification was achieved if the detector remained out of alarm between the time of nuisance initiation and transition to a fire source, and subsequently went into an alarm state between the time of transition to fire and the start of post-test ventilation. The performance of the detectors in relation to their ability to correctly classify the source as a fire or a nuisance is summarized in Table 17. The residential ionization detector did not take data on some tests, because the voltage divider had not been installed and a one-volt difference could not be meaasured from the average background voltage.

Examining the total number of correct classifications for each detector reveals that no detector has a clear advantage over any other detector, although the residential ionization detectors correctly classified a smaller percentage of sources than the rest of the detectors. The table also shows that the prototype detectors may have a slight advantage in classifying fire sources and are comparable in rejecting nuisance sources compared to the Simplex smoke detectors. The residential ionization detector without the cover and bug screen performed the poorest in nuisance rejection, with a success rate of only 33.3%.

Table 18 shows a further breakdown of the classification performance of the detectors to fire sources, showing the difference between flaming fire sources and smoldering fire sources. The prototype detectors performed very well with flaming fire sources, classifying every source correctly, but did not fare as well for smoldering fire sources where the four prototype detectors correctly classified only about half of the sources on average. With the exception of the Simplex Photoelectric detector at Location A, the remainder of the detectors had difficulty in classifying smoldering fire sources.

Table 17. Classification performance of detectors.

Sensor	*Fire Detection*	*Nuisance Rejection*	*Transition Detection (from nuisance to fire)*	*Total*
EWFD 1A	19/23 (82.6%)	6/9 (66.7%)	3/5 (60%)	28/37 (75.7%)
EWFD 2A	19/23 (82.6%)	5/9 (55.6%)	3/5 (60%)	27/37 (73.0%)
Simplex Ion 68 (Location A)	16/23 (69.6%)	5/9 (55.6%)	3/5 (60%)	24/37 (64.9%)
Simplex Photo 53 (Location A)	18/23 (78.3%)	7/9 (77.8%)	3/5 (60%)	28/37 (75.7%)
EWFD 1B	16/23 (69.6%)	8/9 (88.9%)	3/5 (60%)	27/37 (73.0%)
EWFD 2B	15/23 (65.2%)	7/9 (77.8%)	2/5 (40%)	24/37 (64.9%)
Simplex Ion 51 (Location B)	14/23 (60.9%)	6/9 (66.7%)	3/5 (60%)	23/37 (62.2%)
Simplex Photo 50 (Location B)	15/23 (65.2%)	8/9 (88.9%)	3/5 (60%)	26/37 (70.3%)
Residential Ion Detector, without cover and bug screen	19/23 (82.6%)	3/9 (33.3%)	1/5 (20%)	23/37 (62.2%)
Residential Ion Detector	10/21 (47.6%)	5/8 (62.5%)	3/4 (75%)	18/33 (54.5%)

Table 18. Fire source classification performance of detectors.

Sensor	*Flaming Fire Detection*	*Smoldering Fire Detection*
EWFD 1A	12/12 (100.0%)	7/11 (63.6%)
EWFD 2A	12/12 (100.0%)	7/11 (63.6%)
COTS Ion 68 ("A" Location)	12/12 (100.0%)	4/11 (36.4%)
COTS Photo 53 ("A" Location)	9/12 (75.0%)	9/11 (81.8%)
EWFD 1B	12/12 (100.0%)	4/11 (36.4%)
EWFD 2B	12/12 (100.0%)	3/11 (27.3%)
COTS Ion 51 ("B" Location)	11/12 (91.7%)	3/11 (27.3%)
COTS Photo 50 ("B" Location)	10/12 (83.3%)	4/11 (36.4%)
Residential Ion Detector, Chamber only	11/12 (91.7%)	8/11 (72.7%)
Residential Ion Detector	7/10 (70%)	3/11 (27.3%)

8.4 Performance of Prototype Detectors versus Spacing

The prototype detectors were evaluated to determine any changes in performance with respect to their spacing from the fire source. Location A is the detector location closest to the fire source in the Ops Office, and Location B is further away in the far corner of the room. Examination of the classification information presented in Table 17 and 18 shows that the prototypes at Location A were better at detecting fires (primarily ue to better detection of

detecting fires (primarily ue to better detection of smoldering sources), while the prototypes at Location B were better at rejecting nuisances. These results are consistent with expectations based on the detector proximity to the source.

The two prototype locations were also evaluated against average response time as shown in Table 19. These average response times were obtained in the same manner as described in Section 8.2. Overall, the detectors at Location A responded faster to fire tests than the prototypes at Location B, while the B prototypes responded better to nuisance sources (i.e., had longer response times). However, this trend was not always observed. The average response times listed in Table 19 for "Flaming Fire Tests" are based on the same 12 "common alarm" tests for all the detectors, allowing a direct comparison of the response times. For flaming fire sources, prototype EWFD2B had a faster average response than both detectors at Location A. The 2.2m (7.2ft) spacing between the detectors was not very large and will need to be increased in future testing to determine at what distance do substantial differences in performance result.

Table 19. Average response time of detectors versus spacing. (times are in seconds after source initiation)

	Prototype 1		*Prototype 2*	
	EWFD 1A	*EWFD 1B*	*EWFD 2A*	*EWFD 2B*
All Fire Tests	298	378	389	519
Flaming Fire Tests	159	272	161	150
Smoldering Fire Tests	715	694	846	1256
Nuisance Tests[A]	95	321	531	1036
Transition Tests[B]	474	546	487	407

Notes: A – Prototype EWFD1 data for nuisance sources only contains one common alarm
B – The transition tests compasison only includes those where there were *correctly classified* common alarms. This was done so that an early incorrect alarm (during the nuisance phase) did not artificially reduce the average response time.

8.5 Transmission of Data via LAN-based Fiber Optic Ethernet

The last objective of this test series was to demonstrate that the prototype data from the tests could be sent to a remote location (the Control Room in this case), displayed in real-time, and saved to file on the remote computer. In order to accomplish this goal, a computer was set up in the Control Room (02 Deck) with LabVIEW and DataSocket software. This display computer was then directly connected to the fiber optic hub in the control room. The data acquisition computer in the starboard node room was patched into the fiber optic network drop in that room. The LabVIEW setup on the display computer in the Control Room was designed to display the elapsed test time, alarm status of the four prototypes, and plots of the following data versus time: ionization detector output, photoelectric detector output, carbon monoxide level, relative humitidy, RTD temperature, carbon dioxide, and oxygen.

The DataSocketServer software was started on each machine prior to the start of data collection. Once the data acquisition was started on the node room computer, it would automatically broadcast the real-time data information over the fiber optic network. The display computer in the Control Room simply looked for this information and successfully displayed the information as it was received.

9.0 SUMMARY AND CONCLUSIONS

This report documents the results of the Early Warning Fire Detection (EWFD) prototype Series 1 tests conducted on the ex-USS SHADWELL over the period of February 7-18, 2000. Four EWFD prototypes were successfully integrated with a data acquistion system to operate in real time using a probabilistic neural network (PNN) and provided appropriate alarms in real time. Two prototypes were evaluated consisting of different sets of sen sors and a PNN developed based on previous work in this program. EWFD prototype 2 demonstrated slightly better performance than EWFD prototype 1 and faster response times than the Simplex COTS smoke detection system. Even EWFD prototype 1 demonstrated on average faster response times than the Simplex detectors.

The overall classification performance of the prototype PNNs did not show a substantial improvement in source classification over the COTS system. The EWFD prototypes did detect a few more fires than the COTS System, however, nuisance source classification was comparable. The inability to show significant improvement in nuisance source classification can be attributed to several factors. First, the Simplex COTS system was set for optimal nuisance source rejection via use of the alarm verification feature and the EWFD prototypes may have suffered due to the first time use of the System Sensor detectors. Since the PNN alarm algorithms were based on past smoke data from Simplex detectors, there are conversion issues in defining the best correlation between the output signals from the System Sensor and Simplex detectors. In addition, many of the nuisance source tests did not actually result in nuisance alarms for the smoke detectors. Consequently, it is difficult to show improvements in classification with limited data of actual nuisance alarms. Source strength and position with respect to the source will be changed in the next test series to assure that nuisance sources cause nuisance alarms.

The real-time data from the EWFD prototypes was successfully transmitted from the node room over the fiber optic Ethernet and displayed on a computer in the Control room. An increasing delay in the sampling time of the EWFD prototypes was observed over the course of individual tests from 2 to 6 seconds. This delay did not adversely affect the performance of the systems or the quality of the data. However, if additional detectors are to be placed in the system the delays may become excessive. The exact cause of this problem is being investigated and changes will be made for Test Series 2.

10.0 REFERENCES

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APPENDIX A– DATA ACQUISITION SYSTEM

The data acquisition system consisted of a desktop computer (dual Pentium 200Mhz, 128MB RAM, Windows NT 4.0) with data acquisition card (National Instruments AT-MIO-16F-5), and SCXI 1001 Chassis that housed two SXCI 1100 32-Channel amplifier modules. Attached to each module was a SCXI 1303 Terminal block. The three thermocouples used in this test series were connected to channels 0, 1, and 2 of the terminal block attached to the first amplifier module. The remaining sensors were connected to channels 0 to 25 of the terminal block attached to the second amplifier module, as indicated in Table A1.

Table A1. Channel setup on second module of the data acquisition system.

Channel	*Sensor*
0	EWFD 1A System Sensor ionization smoke detector (type 1)
1	EWFD 1A System Sensor photoelectric smoke detector (type 1)
2	EWFD 1A carbon monoxide sensor (0-50ppm)
3	EWFD 1A relative humidity transmitter
4	EWFD 1A carbon dioxide sensor (0-5000ppm)
5	EWFD 2A System Sensor ionization smoke detector (type 4)
6	EWFD 2A System Sensor photoelectric smoke detector (type 4)
7	EWFD 2A carbon monoxide sensor (0-100ppm)
8	EWFD 2A relative humidity transmitter
9	EWFD 2A temperature transmitter
10	EWFD 1B System Sensor ionization smoke detector (type 2)
11	EWFD 1B System Sensor photoelectric smoke detector (type 2)
12	EWFD 1B carbon monoxide sensor (0-50ppm)
13	EWFD 1B relative humidity transmitter
14	EWFD 1B carbon dioxide sensor (0-5000ppm)
15	EWFD 2B System Sensor ionization smoke detector (type 3)
16	EWFD 2B System Sensor photoelectric smoke detector (type 3)
17	EWFD 2B carbon monoxide sensor (0-100ppm)
18	EWFD 2B relative humidity transmitter
19	EWFD 2B temperature transmitter
20	Oxygen sensor
21	Hydrogen sulfide sensor
22	Nitric oxide sensor
23	Hydrocarbon sensor
24	Residential ionization detector – ion chamber only
25	Residential ionization detector

Precision 249Ω resistors were bridged across the terminals of each sensor that provided 4-20mA output, so that the data acquisition could read the results in voltage. Additionally, two voltage dividers were constructed to reduce the output voltage of the residential ionization detectors to the range of the data acquisition system (+5V to –5V). The voltage divider for the standard residential ionization detector (i.e., with cover) was not implemented until test 013,

although this delay only affected results from four tests. The overall setup of the data acquisition system, including the sensors and fiber optic Ethernet connections is shown in Figure A1.

The custom data acquisition software setup required numerous inputs, which are described in Table A2. Note that most of these inputs did not require change from test to test, so they were defaulted to the proper value to benefit the user.

Table A2. Data acquisition software input setup.

Input	*Default Value (if any)*	*Description*
Device	1	Identifies the data acquisition card in the computer
Cold junction channel	ob0!sc1!md1!mtemp	Identifies the channel from which to read the cold junction compensation temperature (used in thermocouple measurements)
Offset channels	ob0!sc1!md1!calgnd ob0!sc1!md2!calgnd	Identifies the channels from which to read the binary module amplifier offsets (used to reference data acquisition to ground). The thermocouple module must be first, followed by the other module.
TC channels	ob0!sc1!md1!0:2	Channels where thermocouples are connected
Other channels	ob0!sc1!md2!0:25	Channels where all the other sensors are connected
TC input limits	0°C to 50°C	Used to set the voltage range from which thermocouple measurements will be made. (does not limit TC readings to this range)
TC type	K	Type of thermocouple used
CJC sensor	Thermistor	Type of sensor used to get the cold junction correction temperature
Voltage input limits	+5V to -5V	Voltage range of the data acquisition system
Alarm probability	(Not defaulted)	Probability threshold for signaling an alarm state
Number of sensors	4	Number of prototype sensors in use
Fire criterion	3	Used in the PNN calculations
Sigma	0.3938[0], 0.4062[1], 0.3938[2], 0.4062[3]	Used in the PNN calculations

Table A2. Data acquisition software input setup. (continued)

Input	*Default Value (if any)*	*Description*
Acquisition delay time	2 sec	Amount of time the data acquisition system pauses between each successive reading of data
Background collection time	1 min	Amount of time used for collecting data before an average of the data is taken as background. The PNN also begins to process data after this time.
Scan rate	5000scans/sec	Rate at which the data acquisition card scans each of the data channels
Number of samples to average	50	Each time data is collected from a channel, the data acquisition system gathers this number of samples from the channel at the Scan rate. The average of this sample is taken as the reading from that channel for that timestep.
Output file path	(Not defaulted)	Path and filename of the output file.
File header	(Not defaulted)	Text header row to put at the top of the output file (should be comma delimited)
Channel / Type	(various)	Identifies to the software what sensor is associated with each channel. Based on this input, the software converts the raw voltage reading to the correct units in real time.

There are several limitations to the data acquisition setup. The software will not operate properly if these guidelines are not followed:

1) Only two amplifier modules may currently be used. This is due to a limitation in the measurement of binary amplifier offsets for each module. The software has been set up to read only two of these values; one for the thermocouple module, and one for the other sensors module. When these channels are specified in the "offset channels" input, the thermocouple module must be listed first. These restrictions currently limit the software to 32 thermocouples and 32 prototype/additional sensors.
2) The software is currently limited to four prototype detectors. The data channels from the prototypes must always be in the same order as listed in Table A1. If less than four prototypes are used, the extra channels may be deleted, but the order from Table A1 must be preserved. For example, if two prototypes were to be used, channels 0-9 as indicated in Table A1 would have to be used, followed immediately by any additional sensors (oxygen, hydrocarbon, etc.) The order of the extra sensors is unimportant, but they must be after the prototype channels. The reason for these limitations is that several data operations are "hardwired" based on an assumed order of sensors.
3) Each prototype must have five sensors. This is another limitation caused by some "hardwiring" of data operations.
4) The data acquisition card is limited to 200,000 total scans per second. Specifying a scan rate per channel which exceeds this limit for the number of channels being scanned will degrade data acquisition performance.

The processing sequence of the data acquisition was as follows:

1) Acquire background data for the length of time indicated by the user (60 seconds was used in these tests). Average values of each of the sensor readings are taken from this backgound data. During this period, the values read from the System Sensor detectors are voltages. The average voltage from the System Sensor detectors is then used to calculate the ΔMIC and %/ft outputs for the ionization and photoelectric detectors, respectively. The remainder of the averages for the other sensors are not used.
2) After the background period has passed, the calculations involved with the probabilistic neural network begin to be executed.
3) Once 25 post-background data points have been taken, alarm probability values are calculated.
4) The data collection continues until stopped by the user.

The output file generated by the data acquisition system was a comma-delimited text file. The test time, individual sensor readings, and probability and alarm conditions for each prototype detector were included in the file. The first row contains the header information for each column (specified in the input "file header"), and each row thereafter is the data taken at the next time. Table A3 gives a complete discription of the output files generated in this test series.

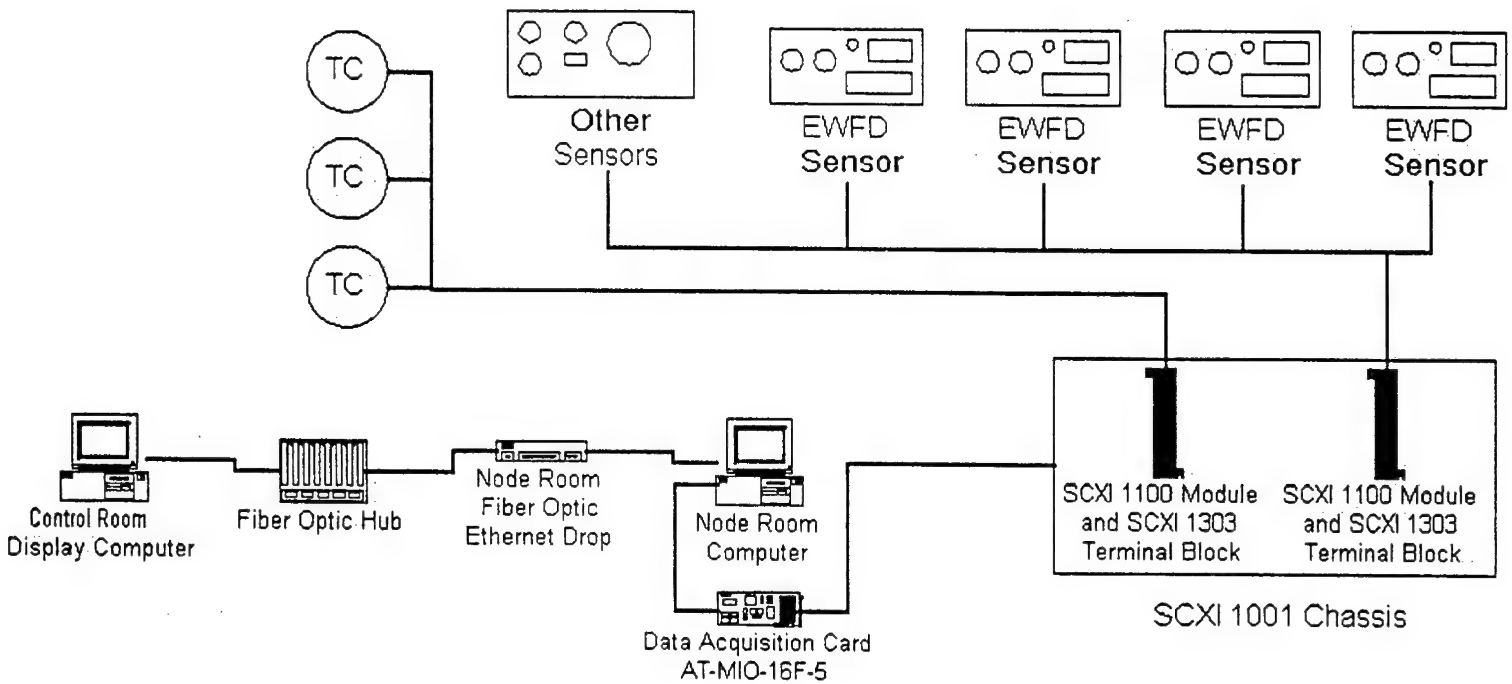
Table A3 – Format of the Output File

Column	*Description*	*Prototype*	*Sensor Range*	*Input Range to Data Acquisition System*	*Units of Values in Ouptut File*
1	Time	-	-	-	Sec
2	Alarm cndition	1A	-	-	1 = ON, 0 = OFF
3	Probability of alarm	1A	-	-	Dimensionless (0-1)
4	System Sensor ion detector	1A	N/A (See Table 6)	0-5V	ΔMIC
5	System Sensor photo detector	1A	N/A (See Table 6)	0-5V	%/ft
6	Carbon monoxide	1A	0-50ppm	1-5V	ppm
7	Relative humidity	1A	0-100%	0-1V	%
8	Carbon dioxide	1A	0-5000ppm	1-5V	ppm
9	Alarm condition	2A	-	-	1 = ON, 0 = OFF
10	Probability of alarm	2A	-	-	Dimensionless (0-1)
11	System Sensor ion detector	2A	N/A (See Table 6)	0-5V	ΔMIC
12	System Sensor photo detector	2A	N/A (See Table 6)	0-5V	%/ft
13	Carbon monoxide	2A	0-100ppm	1-5V	ppm
14	Relative humidity	2A	0-100%	1-5V	%
15	RTD temperature	2A	-20 to 75°C	1-5V	°C
16	Alarm cndition	1B	-	-	1 = ON, 0 = OFF
17	Probability of alarm	1B	-	-	Dimensionless (0-1)
18	System Sensor ion detector	1B	N/A (See Table 6)	0-5V	ΔMIC
19	System Sensor photo detector	1B	N/A (See Table 6)	0-5V	%/ft
20	Carbon monoxide	1B	0-50ppm	1-5V	ppm
21	Relative humidity	1B	0-100%	0-1V	%
22	Carbon dioxide	1B	0-5000ppm	1-5V	ppm
23	Alarm condition	2B	-	-	1 = ON, 0 = OFF
24	Probability of alarm	2B	-	-	Dimensionless (0-1)
25	System Sensor ion detector	2B	N/A (See Table 6)	0-5V	ΔMIC
26	System Sensor photo detector	2B	N/A (See Table 6)	0-5V	%/ft
27	Carbon monoxide	2B	0-100ppm	1-5V	ppm
28	Relative humidity	2B	0-100%	1-5V	%
29	RTD temperature	2B	-20 to 75°C	1-5V	°C
30	Oxygen	-	0-25%	1-5V	%
31	Hydrogen sulfide	-	0-5ppm	1-5V	ppm
32	Nitric oxide	-	0-20ppm	1-5V	ppm
33	Hydrocarbons	-	0-50ppm	1-5V	ppm
34	Residential ion detector, chamber only	-	Unknown	0-5V	Volts

Table A3 – Format of the Output File (continued)

Column	*Description*	*Prototype*	*Sensor Range*	*Input Range to Data Acquisition System*	*Units of Values in Ouptut File*
35	Residential ion detector	-	Unknown	0-5V	Volts
36	Thermocouple at B location	-	-200 to 1350°C	mV	°C
37	Thermocouple at A location	-	-200 to 1350°C	mV	°C
38	Thermocouple at source location 1	-	-200 to 1350°C	mV	°C

Figure A1 - Data Acquisition Setup



APPENDIX B – TEST PROCEDURE

Early Warning Fire Detection Testing

Daily Checklist

Date ____________

VIDEO/AUDIO SYSTEM

_____ Video cameras on
_____ Video display monitors on
_____ Video cassette recorders on, tapes loaded, counters reset
_____ Date/Time generators on, adjust dates or times as necessary

INSTRUMENTATION

_____ Data acquisition systems on
_____ Synchronize computer clock with date/time generators
_____ Data collection program loaded and running

MECHANICAL SYSTEMS

_____ Main fire pumps on
_____ Backup fire pump checked

SAFETY SYSTEMS

_____ Protective clothing in well
_____ OBAs on hand in well
_____ Backup handlines flowed and positioned
_____ PKP extinguisher staged
_____ Ignition torches staged
_____ Two boats available and ready
_____ Coast Guard notified

TEST DAY CONCLUSION

_____ Backup data files to zip disk and set data acquisition for overnight data collection
_____ Video cameras, monitors, and recorders off
_____ Control room power supplies off
_____ Clean and recalibrate ODMs as needed
_____ Secure suppression system water supply

Early Warning Fire Detection Testing

Test Sheet (page ½)

Test Name: EWFD0 ______________ Date:

Description: ____

Ambient Conditions:

Temperature:_____ (F) Rel. Humidity:_____ (%)

Wind Speed:_____ (mph) Wind Direction:________ (degrees)

________ Test area photographed
________ Make announcement: "Attention all personnel, fire testing is in progress. All personnel must clear Frames 15 to 29 on the main, second and third decks."
________ Closure plan in effect. For CIC fires, TPES & TPSS on. For Ops Office fires, TPES only
________ Sound Powered Phone check
  __ Safety officer 1
  __ Safety officer 2
________ Test compartment evacuated (except for fueling personnel)
________ Fire main charged
________ Sink times, Start data acquisition, Reset COTS
________ Start videos
________ Initiate source
________ Fire ignition (if applicable)
________ Test called away
________ Source terminated
________ Stop video recorders
________ Collect 10 minutes of post fire data and background data between tests

Post Test Turnaround
________ Commence post fire shutdown as directed
________ Safety team open doors/hatches to vent test area completely
________ Monitor temperature and sensor data to determine return to baseline conditions

Early Warning Fire Detection Testing

Test Sheet (page 2/2)

Test Name: EWFD0 Date:

NOTES:

Time	Comment

APPENDIX C – ADDITIONAL RESPONSE TIME INFORMATION

Table C1. Response times of the individual system sensor detectors on the EWFD prototypes 1A and 2A (in seconds after source initiation).

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1A Ion			EWFD 1A Photo				EWFD 2A Ion			EWFD 2A Photo			
			4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m	4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m
EWFD_001	fire, flaming	Heptane	132	95	91	DNA	DNA	127	82	245	132	114	DNA	DNA	160	59
EWFD_002	fire, flaming	Pipe insulation and fuel oil	410	360	352	DNA	664	280	275	440	333	317	DNA	646	251	249
EWFD_003	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	66	64	64	326	324	84	52	64	58	56	326	310	56	44
EWFD_004	nuisance/ fire	Burning toast	453	409	400	418	418	391	378	493	427	413	409	409	400	374
EWFD_005	fire, smoldering	Smoldering trash bag	DNA	DNA	DNA	DNA	DNA	1964	657	DNA	DNA	DNA	2835	2824	1849	702
EWFD_006	nuisance	Cigarette smoking	DNA	1710	1640	DNA	DNA	1314	745	DNA	1737	1658	DNA	DNA	1234	226
EWFD_007	fire, flaming	Flaming trashbag, TODCO wallboard	190	181	179	231	231	181	170	194	181	179	224	181	168	165
EWFD_008	fire, flaming	Heptane	146	111	105	DNA	DNA	155	78	256	146	128	DNA	DNA	137	109
EWFD_009	nuisance	Burning popcorn	956	835	356	DNA	DNA	664	559	DNA	870	832	DNA	439	381	318

Table C1. Response times of the individual system sensor detectors on the EWFD prototypes 1A and 2A (in seconds after source initiation) (continued)

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1A Ion			EWFD 1A Photo				EWFD 2A Ion			EWFD 2A Photo			
			4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m	4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m
EWFD_010	fire, flaming	Electrical cable and pipe insulation	148	137	131	396	303	190	168	166	133	129	301	281	181	148
EWFD_011	fire, smoldering	Smoldering electrical cable	2058	1937	1922	DNA	DNA	495	490	DNA	2188	2042	DNA	DNA	493	444
EWFD_012	nuisance	Arc welding	880	836	729	DNA	DNA	324	248	953	858	855	DNA	DNA	281	198
EWFD_013	fire, flaming	Flaming bedding material	DNA	83	72	DNA	DNA	60	58	DNA	60	12	DNA	DNA	30	30
EWFD_014	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	65	52	50	686	683	152	79	83	56	52	671	671	135	36
EWFD_015	Nuisance	Normal toasting	583	536	531	DNA	DNA	DNA	DNA	DNA	1111	598	DNA	DNA	DNA	DNA
EWFD_016	fire, flaming	Small wood crib	DNA	797	321	DNA	1246	239	215	705	251	232	DNA	1246	176	157
EWFD_017	fire, flaming	Trashcan and office chair	438	416	413	491	478	471	392	418	406	396	421	413	387	380
EWFD_018	nuisance	Steel Cutting	237	167	160	DNA	DNA	DNA	DNA	239	156	149	DNA	DNA	DNA	338
EWFD_019	fire, smoldering	Smoldering bedding material	DNA	DNA	1581	DNA	1193	476	465	DNA	DNA	1634	DNA	470	425	420
EWFD_020	fire, smoldering	Printed wire circuit board	DNA	DNA	1833	DNA	DNA	672	634	DNA	DNA	DNA	DNA	DNA	551	498
EWFD_021	fire, smoldering	Brief wire overheat	252	242	239	232	232	232	232	DNA	DNA	DNA	298	295	295	295
EWFD_022	fire,	Smoldering oily	861	858	855	855	852	852	713	861	855	852	845	845	698	659

Table C1. Response times of the individual system sensor detectors on the EWFD prototypes 1A and 2A (in seconds after source initiation) (continued)

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1A Ion 4.2%/m	1.63%/m	0.82%/m	EWFD 1A Photo 11.0%/m	8.0%/m	1.63%/m	0.82%/m	EWFD 2A Ion 4.2%/m	1.63%/m	0.82%/m	EWFD 2A Photo 11.0%/m	8.0%/m	1.63%/m	0.82%/m
	smoldering	rag, newspaper, cardboard in sm. trashcan														
EWFD_023	fire, flaming	Pipe insulation and fuel oil	145	122	118	211	133	86	80	145	101	97	169	86	73	73
EWFD_024	Nuisance	Nylon rope	DNA	1197	1089	DNA	DNA	DNA	DNA	DNA	DNA	1435	DNA	DNA	DNA	808
EWFD_025	nuisance/ fire	Nylon rope into sm. Trashcan	552	537	534	706	706	552	516	555	528	522	709	709	555	537
EWFD_026	fire, smoldering	Smoldering trash bag	197	195	193	213	209	195	195	202	193	193	204	186	177	177
EWFD_027	Nuisance	Burning popcorn	DNA	DNA	DNA	DNA	DNA	477	379	DNA	DNA	DNA	DNA	397	324	309
EWFD_028	nuisance	Steel grinding	DNA	1345	1172	DNA	DNA	823	330	DNA	1539	1257	DNA	DNA	645	521
EWFD_029	fire, smoldering	Smoldering bedding material	DNA	1311	1308	1289	1233	707	655	DNA	1755	23	1068	988	652	605
EWFD_030	nuisance/ fire	Burning toast	399	365	358	410	410	358	347	448	405	381	391	386	360	350
EWFD_031	fire, flaming	Pipe insulation and heptane	117	101	97	103	90	74	70	108	90	88	81	66	61	44
EWFD_032	nuisance	Cigarette smoking	DNA	DNA	1734	DNA	DNA	881	875	DNA	DNA	DNA	DNA	DNA	DNA	954
EWFD_033	fire, smoldering	Printed wire circuit board	DNA	DNA	DNA	DNA	DNA	813	759	DNA	DNA	DNA	DNA	DNA	829	740
EWFD_034	fire, smoldering	Brief wire overheat	DNA	241	239	220	220	218	216	DNA	DNA	DNA	DNA	DNA	DNA	417
EWFD_035	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	503	500	500	495	495	495	495	500	495	495	489	489	489	489

Table C1. Response times of the individual system sensor detectors on the EWFD prototypes 1A and 2A (in seconds after source initiation) (continued)

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1A Ion			EWFD 1A Photo				EWFD 2A Ion			EWFD 2A Photo			
			4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m	4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m
EWFD_036	nuisance/ fire	Arc welding, smoldering plastic trash bag	DNA	3616	839	DNA	DNA	417	380	DNA	3784	639	DNA	DNA	244	200
EWFD_037	nuisance/ fire	Steel cutting, flaming bedding material	125	112	108	DNA	DNA	1109	1004	102	89	87	DNA	DNA	1137	353

Table C2. Response times of the individual system sensor detectors on the EWFD prototypes 1B and 2B (in seconds after source initiation).

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1B Ion			EWFD 1B Photo				EWFD 2B Ion			EWFD 2B Photo			
			4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m	4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m
EWFD_001	fire, flaming	Heptane	623	298	288	DNA	DNA	160	141	245	151	137	DNA	DNA	146	95
EWFD_002	fire, flaming	Pipe insulation and fuel oil	DNA	DNA	1172	DNA	DNA	550	550	426	382	371	DNA	418	296	285
EWFD_003	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	102	92	90	532	382	80	64	74	66	66	330	314	60	56
EWFD_004	nuisance/ fire	Burning toast	574	561	556	471	467	436	431	DNA	579	574	507	502	498	493
EWFD_005	fire, smoldering	Smoldering trash bag	DNA	DNA	DNA	DNA	DNA	2858	1000	DNA	DNA	DNA	DNA	DNA	2903	1742
EWFD_006	nuisance	Cigarette smoking	DNA	DNA	1891	DNA	DNA	DNA	901	DNA	DNA	1737	DNA	DNA	DNA	1371
EWFD_007	fire, flaming	Flaming trashbag, TODCO wallboard	266	255	252	252	245	203	199	201	190	188	226	179	172	168
EWFD_008	fire, flaming	Heptane	781	314	299	DNA	DNA	188	161	218	175	163	DNA	DNA	157	115
EWFD_009	nuisance	Burning popcorn	DNA	939	829	DNA	DNA	433	425	DNA	848	498	DNA	DNA	501	487
EWFD_010	fire, flaming	Electrical cable and pipe insulation	279	239	232	439	320	218	204	166	142	137	310	286	188	166
EWFD_011	fire, smoldering	Smoldering electrical cable	DNA	2103	1967	DNA	DNA	441	399	DNA	2126	1967	DNA	DNA	534	532
EWFD_012	nuisance	Arc welding	DNA	DNA	DNA	DNA	DNA	699	444	DNA	DNA	DNA	DNA	DNA	933	684

Table C2. Response times of the individual system sensor detectors on the EWFD prototypes 1B and 2B (in seconds after source initiation) (continued)

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1B Ion			EWFD 1B Photo				EWFD 2B Ion			EWFD 2B Photo			
			4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m	4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m
EWFD_013	fire, flaming	Flaming bedding material	DNA	DNA	1017	DNA	DNA	187	143	DNA	83	70	DNA	DNA	40	40
EWFD_014	fire, flaming	Oily rag, newspaper, cardboard in sm. trashcan	168	96	87	711	692	152	98	87	62	58	674	668	135	79
EWFD_015	nuisance	Normal toasting	DNA	DNA	1391	DNA	DNA	DNA	DNA	DNA	DNA	618	DNA	DNA	DNA	DNA
EWFD_016	fire, flaming	Small wood crib	DNA	197	173	1227	1194	137	128	274	187	180	DNA	1209	160	126
EWFD_017	fire, flaming	Trashcan and office chair	421	392	384	413	413	375	324	411	382	368	421	411	373	324
EWFD_018	Nuisance	Steel Cutting	DNA	348	335	DNA	DNA	DNA	548	623	611	611	DNA	DNA	DNA	611
EWFD_019	fire, smoldering	Smoldering bedding material	DNA	1647	1481	DNA	DNA	1222	548	DNA	DNA	1541	DNA	DNA	1218	695
EWFD_020	fire, smoldering	Printed wire circuit board	DNA	DNA	DNA	DNA	DNA	576	490	DNA	DNA	DNA	DNA	DNA	687	548
EWFD_021	fire, smoldering	Brief wire overheat	DNA	DNA	DNA	DNA	DNA	DNA	327	DNA	DNA	DNA	DNA	DNA	DNA	322
EWFD_022	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	900	890	890	861	861	842	656	868	861	861	855	855	852	852
EWFD_023	fire, flaming	Pipe insulation and fuel oil	DNA	DNA	751	256	178	125	120	172	142	138	140	125	101	84

Table C2. Response times of the individual system sensor detectors on the EWFD prototypes 1B and 2B (in seconds after source initiation) (continued)

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1B Ion			EWFD 1B Photo				EWFD 2B Ion			EWFD 2B Photo			
			4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m	4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m
EWFD_024	nuisance	Nylon rope	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA	DNA
EWFD_025	nuisance/ fire	Nylon rope into sm. Trashcan	602	580	568	DNA	709	568	528	565	549	546	DNA	DNA	583	537
EWFD_026	fire, smoldering	Smoldering trash bag	234	227	227	225	222	202	200	209	204	202	209	204	193	193
EWFD_027	nuisance	Burning popcorn	DNA	DNA	DNA	DNA	DNA	421	392	DNA	DNA	856	DNA	DNA	540	521
EWFD_028	nuisance	Steel grinding	DNA	1539	1333	DNA	DNA	441	224	DNA	DNA	DNA	DNA	DNA	682	588
EWFD_029	fire, smoldering	Smoldering bedding material	DNA	1781	1628	1304	1103	766	643	DNA	DNA	1712	1289	1289	842	772
EWFD_030	nuisance/ fire	Burning toast	615	545	542	469	467	450	439	585	579	576	542	539	464	453
EWFD_031	fire, flaming	Pipe insulation and heptane	DNA	313	308	222	219	207	202	129	115	113	90	86	74	72
EWFD_032	nuisance	Cigarette smoking	DNA	DNA	DNA	DNA	DNA	DNA	1255	DNA	DNA	DNA	DNA	DNA	DNA	1259
EWFD_033	fire, smoldering	Printed wire circuit board	DNA	DNA	DNA	DNA	DNA	768	681	DNA	DNA	DNA	DNA	DNA	967	866
EWFD_034	fire, smoldering	Brief wire overheat	DNA	DNA	DNA	DNA	DNA	DNA	370	DNA	DNA	DNA	DNA	DNA	DNA	428
EWFD_035	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. trashcan	539	531	531	509	509	506	506	509	503	503	495	495	495	495
EWFD_036	nuisance/ fire	Arc welding, smoldering plastic trash bag	DNA	3732	3605	DNA	DNA	476	342	DNA	DNA	3662	DNA	DNA	535	407

Table C2. Response times of the individual system sensor detectors on the EWFD prototypes 1B and 2B (in seconds after source initiation) (continued)

TEST	TYPE	BRIEF DESCRIPTION	EWFD 1B Ion			EWFD 1B Photo				EWFD 2B Ion			EWFD 2B Photo			
			4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m	4.2%/m	1.63%/m	0.82%/m	11.0%/m	8.0%/m	1.63%/m	0.82%/m
EWFD_037	nuisance/ fire	Steel cutting, flaming bedding material	1432	269	259	DNA	DNA	1198	1028	1377	156	153	DNA	1495	1362	1354

Table C3. Average response time of system sensor detectors (as part of EWFD prototypes) compared to the simplex (COTS) detectors (times are in seconds after source initiation).

Fire Tests (all)	EWFD1 A Ion	EWFD2 A Ion	COTS Ion 68 - "A" Loc.	EWFD 1A Photo	EWFD2A Photo	COTS Photo 53 - "A" Loc.	EWFD1 B Ion	EWFD2 B Ion	COTS Ion 51 - "B" Loc.	EWFD1B Photo	EWFD2B Photo	COTS Photo 50 - "B" Loc.
23	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m
Number of alarms	15	14	16	16	16	19	10	14	14	12	13	14
Common alarms	13	13	13	15	15	15	10	10	10	11	11	11
Average response time (sec)	263	283	230	558	478	480	431	299	273	556	538	436
Standard Deviation	230	222	235	406	344	322	270	241	244	358	420	282
Fire Tests (flaming)	EWFD1 A Ion	EWFD2 A Ion	COTS Ion 68 - "A" Loc.	EWFD 1A Photo	EWFD2A Photo	COTS Photo 53 - "A" Loc.	EWFD1 B Ion	EWFD2 B Ion	COTS Ion 51 - "B" Loc.	EWFD1B Photo	EWFD2B Photo	COTS Photo 50 - "B" Loc.
12	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m
Number of alarms	10	11	12	9	9	10	7	11	11	8	9	10
Common alarms	10	10	10	9	9	9	7	7	7	8	8	8
Average response time (sec)	186	212	147	461	433	455	377	200	163	455	410	310
Standard Deviation	131	131	130	362	374	363	247	113	99	339	372	175
Fire Tests (smolder)	EWFD1 A Ion	EWFD2 A Ion	COTS Ion 68 - "A" Loc.	EWFD 1A Photo	EWFD2A Photo	COTS Photo 53 - "A" Loc.	EWFD1 B Ion	EWFD2 B Ion	COTS Ion 51 - "B" Loc.	EWFD1B Photo	EWFD2B Photo	COTS Photo 50 - "B" Loc.
11	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m
Number of alarms	5	3	4	7	7	9	3	3	3	4	4	4
Common alarms	3	3	3	6	6	6	3	3	3	3	3	3
Average response time (sec)	520	521	506	702	546	519	558	529	528	824	880	771
Standard Deviation	332	330	325	459	312	279	333	330	315	299	398	242

Table C3. Average response time of system sensor detectors (as part of EWFD prototypes) compared to the simplex (COTS) detectors (times are in seconds after source initiation) (continued)

Nuisance Tests	EWFD1 A Ion	EWFD2 A Ion	COTS Ion 68 - "A" Loc.	EWFD 1A Photo	EWFD2A Photo	COTS Photo 53 - "A" Loc.	EWFD1 B Ion	EWFD2 B Ion	COTS Ion 51 - "B" Loc.	EWFD1B Photo	EWFD2B Photo	COTS Photo 50 - "B" Loc.
9	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m
Number of alarms	4	2	4	0	2	3	0	1	3	0	0	1
Common alarms	2	2	2	0	1	1	-	1	1	-	-	1
Average response time (sec)	559	596	467	-	397	432	-	623	125	-	-	674
Standard Deviation	455	505	500	-	-	-	-	-	-	-	-	-
Nuisance/Fire Tests	EWFD1 A Ion	EWFD2 A Ion	COTS Ion 68 - "A" Loc.	EWFD 1A Photo	EWFD2A Photo	COTS Photo 53 - "A" Loc.	EWFD1 B Ion	EWFD2 B Ion	COTS Ion 51 - "B" Loc.	EWFD1B Photo	EWFD2B Photo	COTS Photo 50 - "B" Loc.
5	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m	4.2%/m	4.2%/m	4.2%/m	8.0%/m	8.0%/m	8.0%/m
Number of alarms	4	4	4	3	3	3	4	3	4	3	3	3
Common alarms / Correct	3	3	3	2	2	2	2	2	2	2	2	2
Average response time (sec)	468	499	470	414	398	462	609	575	486	467	521	483
Standard Deviation	78	54	27	6	16	11	9	14	45	0	26	6

Table C4. Summary of average response time of the prototype detectors and the simplex detectors. (times are in seconds after source initiation)

Fire Tests (all) 23	EWFD1A	EWFD2A	COTS Photo 53 - "A" Loc.	COTS Ion 68 - "A" Loc.	EWFD1B	EWFD2B	COTS Photo 50 - "B" Loc.	COTS Ion 51 - "B" Loc.
Number of alarms	20	19	19	16	16	22	14	14
Common alarms	14	14	14	14	11	11	11	11
Average response time (sec)	431	375	665	476	374	262	444	283
Standard Deviation	712	518	703	751	311	242	242	245
Fire Tests (flaming) 12	EWFD1A	EWFD2A	COTS Photo 53 - "A" Loc.	COTS Ion 68 - "A" Loc.	EWFD1B	EWFD2B	COTS Photo 50 - "B" Loc.	COTS Ion 51 - "B" Loc.
Number of alarms	12	12	10	12	12	12	10	11
Common alarms	10	10	10	10	9	9	9	9
Average response time (sec)	168	169	497	224	303	167	392	195
Standard Deviation	113	104	367	257	287	99	222	139
Fire Tests (smolder) 11	EWFD1A	EWFD2A	COTS Photo 53 - "A" Loc.	COTS Ion 68 - "A" Loc.	EWFD1B	EWFD2B	COTS Photo 50 - "B" Loc.	COTS Ion 51 - "B" Loc.
Number of alarms	8	7	9	4	4	10	4	3
Common alarms	4	4	4	4	2	2	2	2
Average response time (sec)	1088	892	1086	1105	364	358	250	366
Standard Deviation	1165	795	1185	1226	213	214	354	197
Nuisance/Fire Tests 5	EWFD1A	EWFD2A	COTS Photo 53 - "A" Loc.	COTS Ion 68 - "A" Loc.	EWFD1B	EWFD2B	COTS Photo 50 - "B" Loc.	COTS Ion 51 - "B" Loc.
Number of alarms	4	4	3	4	4	5	3	4
Common alarms / Correct	2	2	2	2	1	1	1	1
Average response time (sec)	444	442	462	454	531	292	479	454
Standard Deviation	13	11	11	6	-	-	-	-